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16. ABSTRACT

Pertinent to the implementation of State and areawide planning under Section 208 of P.L. 92-500, this manual provides an environmental management statement of procedures available for water quality management with particular emphasis on urban stormwater. The manual summarizes and presents in condensed form a range of available procedures and methodologies that are available for identifying and estimating pollutant load generation and transport from major sources within water quality management planning areas. Although an annotated chapter is provided for the assessment of non-urban pollutant loads, the major emphasis of the manual is directed toward the assessment of problems and selection of alternatives in urban areas, with particular concern for stormwater related problems. Also included in the manual are methodologies for assessing the present and future water quality impacts from major sources as well as summaries of available information and techniques for analysis and selection of structural and nonstructual control alternatives.

This manual is structured to present problem assessment and impact analysis approaches for several levels of planning sophistication. Simple procedures are recommended for initial analysis to develop the insight and problem understanding to guide the application of more complex techniques where required. Presented in three volumes the specific sections are as follows: procedures for assessment of urban and non-urban pollution sources and loadings, pollutional load stream impact analysis, methodology for evaluation and selection of control alternatives, rainfall runoff and water quality model applicability, land use and rainfall data analysis, runoff and water quality monitoring and parameter handbook, and cost and performance of structural and nonstructural pollution control alternatives.

17. KEY WORDS AND DOCUMENT ANALYSIS

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DISCLAIMER

This manual has been reviewed by the Office of Research and Development (Municipal Environmental Research Laboratory - Cincinnati, and Environmental Research Laboratory - Athens) and by the Office of Water and Hazardous Materials (Water Planning Division) and is approved for publication.

In approving the first edition of this manual both the Office of Water and Hazardous Materials and the Office of Research and Development emphasize that the information contained herein represents a summarization of selected state-of-the-art assessment procedures and impact analysis techniques that are considered useful and supportive of the objectives of the areawide wastewater planning and management programs.

The contents of the manual are intended to be informative rather than prescriptive in nature and in no way should be considered mandatory. Approval does not signify that the contents necessarily reflect the views of the Environmental Protection Agency nor does mention of trade names or propriety approaches constitute endorsement or recommendation for use.

EPA-600/9-76-014 I
July 1976

AREAWIDE ASSESSMENT PROCEDURES MANUAL

VOLUME I

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
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TO: Users of the Areawide Assessment Procedures Manual

The implementation of State and areawide planning under Section 208 of P.L. 92-500 has created a demand for sound technical analyses within a relatively short period of time. As new information becomes available from research efforts, it is important that it be applied where possible to our environmental management efforts. This manual was produced as a joint effort between EPA's Office of Research and Development and the Office of Water Planning and Standards. It provides a statement of procedures available for water quality management, with particular emphasis on urban stormwater. This publication contains the first sections of a manual that will be mailed in three parts. This first mailing includes a description of some of the basic procedures which could be utilized during the early stages of a study to determine whether more complex analyses are warranted.

As point sources are abated, an increased concern has developed on the need for controlling nonpoint sources of pollution. For effective water quality management, it is often necessary to analyze the relative contribution of different pollution sources so that coordinated structural and non-structural control programs can be proposed. This manual suggests procedures which should lead to practical decisions, based on the assumption that the simplest techniques can often produce the necessary information that is to be used. Thus the manual describes several techniques which are representative of different levels of sophistication which may be required for both problem assessment and the evaluation of alternatives. The implementation of environmental programs requires both a sound technical justification as well as local political support; therefore, the desirable plan may not necessarily represent the optimal solution in the strictest sense, but rather a pragmatic solution which will be implemented and result in improved or preserved water quality.

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Deputy Assistant Administrator
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ABSTRACT

This manual summarizes and presents in condensed form a range of available procedures and methodologies that are available for identifying and estimating pollutant load generation and transport from major sources within water quality management planning areas. Although an annotated chapter is provided for the assessment of non-urban pollutant loads, the major emphasis of the manual is directed toward the assessment of problems and selection of alternatives in urban areas, with particular concern for stormwater related problems. Also included in the manual are methodologies for assessing the present and future water quality impacts from major sources as well as summaries of available information and techniques for analysis and selection of structural and non-structural control alternatives.

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This manual has been prepared by the Environmental Protection Agency, Office of Research and Development, Municipal Environmental Research Laboratory, Cincinnati, in collaboration with the Office of Water and Hazardous Materials, Water Planning Division. Significant technical contribution and direction has been provided by the following EPA programs:

- Environmental Research Laboratory, Office of Air, Land and Water Use, Athens, Georgia.
- Environmental Monitoring and Support Laboratory, Office of Monitoring and Technical Support, Las Vegas, Nevada.

In addition to EPA staff contributions, portions of this manual have also been prepared in whole or in part by the organizations listed below:

- Hydroscience, Inc., Westwood, New Jersey.
- Battelle Columbus Laboratories, Columbus, Ohio.
- Roy F. Weston, Inc., West Chester, Pennsylvania.
- EG&G Washington Analytical Services Center, Inc., Rockville, Maryland.
- Metcalf & Eddy, Inc., Palo Alto, California.

FOREWORD

The enactment of Public Law 92-500 marked a new era of environmental awareness in the United States. A vital part of this legislation is the provision for areawide waste treatment management planning under Section 208. The Congressional intent of Section 208 was to establish a planning framework necessary to meet the 1983 National Water Quality Goals in highly urbanized areas or non-urban environments where complex water quality problems exist.

In establishing an overall wastewater management plan, state and areawide planning agencies must examine the wide variety of pollutant sources and corresponding receiving water impacts in the planning area in light of the necessity and feasibility of their control. The most successful approach will likely be one that integrates ongoing and projected point source pollution control measures with cost-effective combinations of management and structural alternatives for nonpoint source pollution control.

This Areawide Assessment Procedures Manual, produced jointly by EPA's Water Planning Division and Office of Research and Development, is one of a number of guidance and information documents developed to support the Agency's 208 areawide waste treatment management and planning effort. The manual summarizes selected state-of-the-art problem assessment methodologies and approaches that are useful in achieving the goals and objectives of state and areawide water quality management and planning. Future editions of this manual are planned as new areawide assessment procedures and methodologies are further developed and verified.

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MANUAL DISTRIBUTION RECORD

The Areawide Assessment Procedures Manual is prepared as one of a number of information documents developed to support the Agency's 208 areawide waste treatment management and planning effort. The complete Manual is presented in a three volume format to facilitate its use. Because the Manual is being prepared and distributed in separate mailings, and because it is anticipated that some chapters or appendices will be revised in the future, it is necessary that the recipient of this portion of the Manual enter a "Register of Manual Users."

In order for your name to be entered into the Register and therefore be placed on the mailing list for future Manual additions and/or revisions, the accompanying form, EPA-291(Cin)(7/76), must be filled out. The correct information must be entered into the following blocks of the Form: TITLE (Dr., Mr., Ms., etc.), LAST NAME (Omit professional titles), FIRST NAME, I (i.e., middle initial), COMPANY NAME, ADDRESS LINES ONE, TWO, THREE (i.e., company address), CITY, ST (acceptable 2-character state abbreviation), and ZIP, (must be entered).

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CHAPTER 1

INTRODUCTION

1.1 Purpose of the Manual

When Congress passed the Federal Water Pollution Control Act Amendments of 1972 (the Act), it was recognized that a number of water pollution control problems in the United States are so complex that they cannot be solved by traditional engineering evaluation and technology application alone. In most cases, these problems involve urban areas where population and industry are concentrated and where inter-relationships exist between receiving water quality, point source discharges, intermittent point loads from combined sewer overflows, and urban stormwater runoff. The situation may be further complicated and sometimes dominated by nonpoint source contaminant contributions from rural areas outside of the urban fringe, or by the receiving water impacts of construction activities, mining, or residuals management practices.

Section 208 of the Act provides a mechanism for the planning and management necessary to achieve the 1983 goals in these complex regional situations. The purpose of Section 208 is to facilitate the development and implementation of areawide waste management plans at the local level in designated areas and by the state outside such areas. As of September 1976, Federal assistance funds have been provided at 75 to 100 percent of eligible project costs to 176 designated planning agencies for the preparation of initial areawide plans addressing the complex issues.

Early in the water quality management planning program, which began with the award of the first grants in the Spring of 1974, a strong need developed at the designated agency level for technical assistance in the assessment of pollutant loads, receiving water impacts and control alternatives, particularly with regard to nonpoint and intermittent point source loads in the urban environment. As more planning agencies have entered the 208 program, this need has increased even more, in spite of the experience gained by early groups.

To a large degree, the need results from the hydrologic and pollutant generation complexity of urban areas. Each situation is unique, requiring a range of analytic approaches which cannot necessarily be transported from one study area to another. But the major problem has been the fact that there is no established technical framework for analysis of complicated urban wastewater problems. A wide range of methodologies from many sources exists, but many of these are inappropriately applied in planning programs at the sacrifice of time, expense, manpower and plan accuracy.

The objective of this Areawide Assessment Procedures Manual is to provide a unified technical framework for the analysis of complex areawide wastewater problems. A range of useful assessment approaches is evaluated and arrayed within this framework. To the greatest extent possible, an attempt has been made to consolidate selected state-of-the-art information into a single guide. The document stresses approaches to urban problems, but also discusses assessment methodologies for non-urban, nonpoint source pollution problems to the extent needed to put these problems into relative perspective in the overall areawide waste treatment plan. Methods for evaluating the receiving water impact and economic feasibility of alternative pollution control strategies, including non-structural management practices for urban stormwater control, are also provided.

It is especially important to understand that the Areawide Assessment Procedures Manual does not present a required methodology or suggest administrative planning procedures which must be followed. It is a technical assistance and reference document intended for use by designated local planning agencies, state planning bodies and planning and engineering firms involved in areawide waste treatment management planning. It will also be useful to municipal agencies concerned with stormwater management.

The discussion and evaluation of selected present day pollution assessment methods, models, etc., here does not mean that other techniques are not equally useful. The manual will be regularly updated as new techniques are developed and as the results of practical application become available. It is also important to recognize that the document does not specifically concern itself with the institutional, political or legal aspects of areawide waste management planning. These are the subject of other assistance documents soon to be published by the EPA Water Planning Division, Office of Water and Hazardous Materials.

1.2 Relationship of the Manual to Agency Policy, Legal and Regulatory Requirements and Guidance Documents

In assuming its responsibilities for the implementation of the Act, the Environmental Protection Agency has published regulations, policies and guidance documents on water pollution abatement for use by individuals in the private sector and by responsible public officials. While the Areawide Assessment Procedures Manual is not an administrative policy or regulations document, it is important for those who will use it in areawide water quality management planning to understand its relationship to the requirements of such documents. This is particularly true in regard to the question of urban stormwater management policy, which may be less well understood by state and local planners than the more familiar requirements for point source control, effluent limitations, or funding requirements for state and local 208 grants. Several recent developments regarding this policy are discussed briefly below, with special emphasis upon those policies affecting the potential need for application of the assessment procedures of this manual.

1.2.2 Stormwater Management Policy

As the Nation's point source pollution control program nears the end of its first stage, it is becoming more apparent that trade-offs must be made between more advanced treatment of continuous point sources and control of nonpoint source pollution. Among diffuse sources of pollution, stormwater runoff has been identified as one of the major contributors to water pollution in urban areas. Although treatment technology is available for managing the stormwater problem, estimated National costs for implementation of such treatment are prohibitive, ranging from $153 billion to $600 billion. There is little doubt that there may be substantial inaccuracy in these figures. This results from the variability of costing approaches and treatment efficiency assumptions used, and the fact that, in spite of a variety of past assessment studies, the total relationship between urban runoff and receiving water quality is not clearly understood. Nonetheless, it is clear that alternatives other than traditional forms of treatment should be considered.

A more effective approach for stormwater pollution abatement in urban areas is the implementation of nonstructural stormwater management practices in coordination with only the most cost-effective structural control options. This approach may offer pollution abatement potential similar to the various treatment alternatives available, but at a significantly reduced cost.

Stormwater management practices, often termed Best Management Practices (BMPs) fall into two groups: those most useful for existing or developed areas and those more applicable to new or developing areas. In the former instance, BMP embodies "reduction" techniques such as street sweeping, improved waste collection and improved sewer maintenance practices and sewer system management practices to reduce or attenuate stormwater flows to receiving waters. A preventative concept best applies to developing urban areas where the objective should be to manage new development in order to contain or attenuate runoff flows and limit the potential for unnatural pollutant contribution to receiving waters. Techniques in these areas include improved construction site management; provision for groundwater recharge; construction of detention basins; and playground, parking lot, or rooftop storage of stormwater.

1.2.3 Funding and Legal Requirements

The need for the thorough development of comprehensive urban/areawide wastewater management plans has been amplified by a recent court action and by the Agency's further interpretation of stormwater regulations.

As a result of a June 10, 1975, decision of the Federal District Court for the District of Columbia (NRDC versus Train) the Agency is required to apply the National Pollutant Discharge Elimination System (NPDES) permit program to separate storm sewers. Regulations for implementing this decision were finalized in December 1975 (40 FR 56932). In accordance with these regulations certain storm sewers that were once exempt due to nonpoint source status are now considered point sources, for which general permits will be issued. In addition, respective permitting authorities may on a case-by-case basis require the owner-operator of any separate storm sewer to obtain a conventional NPDES permit.

Under these new regulations it has become increasingly important that urban runoff from separate storm sewers be adequately included as a part of the areawide planning process. It is also important for planners to realize that the regulations have expanded the definition of a "separate storm sewer" to mean "a conveyance or system of conveyances (including but not limited to pipes, conduits, ditches and channels) located in an urbanized area and primarily operated for the purpose of collecting and conveying stormwater runoff." (Title 40, Chapter 1, Part 124, Part 125, Federal Register, Vol. 41, No. 54, May 18, 1976).

The Agency has also provided policy direction regarding the use of construction grants for providing treatment and control of combined sewer overflows and stormwater discharges during wet-weather conditions. This policy has significant implications upon the degree of stormwater analysis conducted in 208 planning and upon the nature of stormwater control alternatives proposed in the final water quality plan.

Construction grant funds may be approved for the control of pollution from combined sewer overflows, but only after thorough, detailed wastewater treatment planning for the 20-year planning interval has been completed and has adequately considered the following:

(1) the effectiveness of alternative control techniques or management practices,

(2) the costs of achieving various levels of pollution control with each feasible technique,

(3) the benefits to the receiving waters of a range of levels of pollution control during wet-weather conditions, and

(4) the costs and benefits resulting from the addition of advanced waste treatment processes to dry-weather flows in that area.

Where detailed areawide planning has been completed, treatment or control of wet-weather overflows and by-passes may be given priority for construction grant funds only after provision has been made for secondary treatment of dry-weather flows in the area. For control or treatment of separate discharges of stormwater, however, the Agency's current policy is that construction grants shall not be available except under unusual conditions where a project situation has clearly been shown to meet the detailed planning and evaluation criteria for combined sewer overflow grants.

Projects with multiple purposes in addition to pollution control, such as flood control and recreation, may be eligible for grant amounts not to exceed the cost of the most cost-effective single pollution abatement system.

1.2.4 Relationship to Other Technical Guidance Documents for Areawide Planning

This Areawide Assessment Procedures Manual is one of several publications issued or in preparation to assist the Water Planning Division of the EPA Office of Water and Hazardous Materials to provide technological guidance and information to those involved in areawide water quality management planning.

A distinguishing feature of this manual is that it is more comprehensive in scope than many of the previously issued assistance documents. It represents the first of a series of information documents to be issued for use in technical 208 planning efforts which will also include management practice guidelines and pollution assessment methods for mining activities, non-irrigated agriculture, silviculture, hydrographic modifications, construction activities, and residuals management practices. These documents are currently in preparation.

1.3 Guide for Use of the Manual

1.3.1 Intended Users

The Areawide Assessment Procedures Manual is intended to be used as a comprehensive technical reference and planning assistance document for use by a wide range of individuals involved with various stages of the 208 planning process. The potential user community includes: administrators, planning directors and technical planners at designated 208 agencies; state environmental quality officials and individuals responsible for statewide 208 plans; private firms providing consulting services to 208 planning efforts; Federal and state officials responsible for the review and evaluation of areawide plans; and other public institutions responsible for the management of urban drainage systems.

This is not to imply that the entire manual will be equally useful to all people. Various portions will be useful to each of these groups at various stages of the planning cycle. The manual does not have to be read from cover to cover to be of use in the planning process.

For those designated local agencies in the formative stages of their planning program, the preliminary assessment concepts, technical reference material and cost information throughout the document will be very helpful. Planning directors or administrators will probably find the preliminary problem assessment sections of greatest use, especially in the sense that problem identification in the early project stages will help clarify staffing needs, suggest more efficient allocation of limited resources among highest priority problems, and assist in the generation of an effective work approach. Technical planners, engineers and consultants on the other hand will have a greater interest in the assessment methods, evaluation sections, and the Appendix information.

It is fully recognized that the utility of the manual will also vary from one planning organization to another depending upon its stage in the planning process and its regional environmental planning approach. Overall, the manual will have the greatest impact upon those groups who are still developing their approach to assessing urban/areawide water quality problems. Organizations nearing completion of their 208 plans, or those with well established comprehensive regional assessment approaches will make greater use of the sections dealing with advanced assessment methods, the evaluation of alternative control strategies, and management practices for urban stormwater control. For those designated agencies already contractually committed to a particular planning direction the information throughout the manual will enable more effective technical communication with and direction of their consulting organizations.

1.4 Organization of the Manual

1.4.1 Rationale of Approach

An acknowledged fact of areawide planning is that the problems and needs of no two planning areas are exactly the same. Similarly, problems within a planning area have varying degrees of priority and complexity. Consequently, there is no universally applicable assessment tool for the analysis and solution of these problems. Rather, there are a variety of useful methods of varying cost, accuracy and sophistication which planners must apply in a successful assessment program.

This manual recognizes this fact by establishing a sequential assessment approach beginning with a gross, first-cut analysis designed to determine the relative magnitudes, and spatial and temporal distribution of major pollution problems in an area. These analyses are intended to rely only upon existing or readily available data bases and are designed to help the planner avoid overly sophisticated, expensive and often unnecessary efforts in areas where certain problems are not critical. Once the planner has identified the critical parameters and problem areas for his region, he may then refer to the appropriate higher order analyses which are presented in subsequent sections of the manual.

1.4.2 Chapter Content

The content of each of the respective chapters of this manual is outlined below:

Chapter 1 - "Introduction"

Chapter 2 - "Data Base Inventory and Preliminary Problem Identification": indicates basic data requirements and procedures necessary for preliminary problem identification and assessment in order to define those additional technical steps necessary for development of an effective areawide plan. Techniques are presented to assess the magnitude and impact of various classes of waste sources, urban and non-urban, on water quality under various seasonal and hydrologic conditions.

Chapter 3 - "Procedures for Urban Assessment of Pollutant Sources and Loadings": provides illustrative alternative procedures which are available to assess, in additional detail, the magnitude of urban wastewater loads. Procedures are discussed for definition of continuous municipal and industrial point source loads, intermittent rainfall related combined sewer overflows and stormwater discharges and generalized nonpoint source urban runoff. Two alternative technical approaches are discussed for estimation of stormwater related waste flow and quality.

Chapter 4 - "Procedures for Non-Urban Assessment of Pollutant Sources and Loadings": describes more detailed procedures to determine the quantity and quality of non-urban nonpoint sources. Methods of estimating seasonal variations in the flow and quality of runoff originating from agricultural and forrested areas are discussed. In addition, nonpoint source loadings from other diverse activities including construction, residuals disposal, mining and irrigated return flows are described.

Chapter 5 - "Analysis of Stream Impacts for Urban and Non-Urban Sources": summarizes methods of analysis which are available to determine the impact of urban and non-urban wastewater sources on the quality of receiving waters. Different types of receiving water bodies are described along with time and space scales of water quality problems. Steady state and time varying water quality modeling approaches are discussed as well as single and multi-dimensional analytical networks. Data requirements, parameter evaluation, calibration and verification techniques are described. The use of the various techniques is related to the urban and non-urban loading assessment methodology discussed in Chapters 3 and 4.

Chapter 6 - "Evaluation and Selection of Control Alternatives": a matrix of controllable and uncontrollable sources for critical pollutants from urban and non-urban areas is presented along with methods of ranking structural and nonstructural alternatives for load reduction. Procedures to develop a least cost mix of structural and nonstructural solutions to meet desired water quality goals are identified.

Chapter 7 - "Examples of Assessment Methodology for Urban and Non-urban Areas": a data base inventory and problem identification for urban and non-urban assessments with comparative evaluations of mass pollutant loadings and stream impacts are provided. Additionally, a summary presentation and selection of control alternatives is given.

1.4.3 Use and Content of Appendices

The ten appendices are intended to be supportive of the information presented in the Chapters. However, each appendix is written for separate identifiable subjects and may also be used independent of the text of the manual.

The following briefly describes the content of each appendix.

Appendix A - "Model Applicability Summary": this appendix contains a summary of computer-based mathematical tools available to areawide water quality planners. In addition, an explanation and data input needed for each model is presented in order to help in the evaluation and selection of the most effective model.

Appendix B - "Water Quality Data Bases": the availability and value of various water quality data bases are discussed in terms of their use in the areawide water quality planning process.

Appendix C - "Land Use Data Bases and Methods": a range of specific techniques and qualitative methods for land use data collection, management and analysis in areawide water quality management planning is described. A descriptive survey of alternative approaches to the land use element of the 208 planning process, from relatively simple techniques to complex ones, is provided.

Appendix D - "Monitoring Requirements, Methods and Costs": the best available technical information for the design, management, and execution of water pollution control monitoring of interest to 208 planning agencies is organized and packaged in readily usable form. Descriptions of the manpower, equipment, and technical methodology requirements and associated costs are also presented.

Appendix E - "Statistical Analysis Procedures and Methods": compatible methods for the statistical analysis of climatic data, stream flow, pollutant accumulation and rainfall events are described.

Appendix F - "Water Quality Standards": a summary of current water quality standards is presented along with information and problems for interpretation and incorporation of these standards into receiving water quality analysis.

Appendix G - "Best Management Practices": currently available performance and cost data for urban stormwater management practices is summarized and evaluated in light of its applicability in the development of an areawide stormwater abatement program.

Appendix H - "Structural Cost Analysis Models and Procedures": a concise and definitive summary of the capital and O&M costs of all available structural solutions to waste management problems. This appendix also presents a step-by-step methodology for identification, evaluation, and selection of the most cost-effective combination of structural and non-structural control alternatives in urban areas. This Appendix appears as Volume III of this manual.

Appendix I - "Bibliography": an annotated bibliography of publications frequently useful in areawide water quality management planning is presented.

Appendix J - "Glossary of Terms": the glossary is intended to provide a definition of technical terms used throughout the Areawide Assessment Procedures Manual which might not be readily known by the wide user community anticipated.

1.5 Schedule of Mailings

The need for the Areawide Assessment Procedures Manual is an immediate one. Because of the magnitude of the effort, it would be untimely to withhold distribution of critical portions of the manual until the entire document is completed. Consequently, those portions of the manual which the Agency believes are most essential to the majority of designated agencies at this point in the planning cycle (September 1976) will be distributed first. Table 1-1 describes the anticipated contents and timing of subsequent distributions aimed at completing the manual by January 1977.

TABLE 1-1
SCHEDULE OF MAILINGS FOR THE AREAWIDE ASSESSMENT PROCEDURES MANUAL

Mailing Number 1 - September 1976

Volume I: Chapter 1 - Introduction
Chapter 2 - Preliminary Problem Assessment
Chapter 3 - Procedures for the Assessment of Urban Pollutant Sources and Loads

Volume II: Appendix A - Model Applicability Summary
Appendix C - Land Use Data Collection and Analysis

Mailing Number 2 - December 1976

Volume I: Chapter 4 - Procedures for the Assessment of Non-Urban Pollutant Sources and Loadings
Chapter 5 - Analysis of Receiving Water Impacts of Urban and Non-Urban Sources

Volume II: Appendix B - Water Quality Data Bases
Appendix D - Monitoring Requirements, Methods, and Costs
Appendix E - Statistical Analysis Procedures and Methods
Appendix F - Water Quality Standards
Appendix G - Best Management Practices
Appendix I - Bibliography
Appendix J - Glossary of Terms

Mailing Number 3 - January 1977

Volume I: Chapter 6 - Evaluation and Selection of Control Alternatives
Chapter 7 - Examples of Assessment Methodology for Urban and Non-Urban Areas

Volume II: Appendix H - Structural Cost Analysis Models and Procedures

CHAPTER 2

PRELIMINARY PROBLEM ASSESSMENT

2.1 Introduction

In the past, many wastewater and water quality management studies have been concerned with readily identifiable and controllable point sources of wastewater discharge, principally of municipal and industrial origin. The underlying assumption in many of these studies was that the most severe water quality problems, particularly dissolved oxygen effects, were likely to occur during relatively dry, low flow periods where municipal and industrial treatment plant discharges would have a predominant influence on receiving water quality. In most circumstances, water quality effects which could not be directly related to the point sources under study were considered as natural or background effects to be considered as baseline water quality conditions. Wastewater management activities were then concentrated on readily identifiable and controllable point sources to improve water quality to the extent practical. As a result, many of these studies resulted in the development of waste load allocations for municipal and industrial point sources for water quality control during periods of specified low river flow and background water quality.

In certain cases, the results of this type of analysis are satisfactory for effective water quality management. It is recognized, however, that in many areas, overall long term water quality improvement requires consideration of other factors in addition to municipal and industrial point sources control. Even under low flow conditions, the background water quality used as a baseline in the development of point source waste load allocations may be subject to improvement if the sources which control background water quality can be identified and controlled in a cost-effective manner. Further, during periods of the year other than low stream flow, water quality may be impaired by wastewater contributions from a variety of sources in addition to municipal and industrial effects. Discharges from intermittent point sources such as combined sewer overflows, stormwater drainage, urban runoff, and numerous non-urban non-point sources may all contribute to the degradation of a number of water quality variables in the receiving water in differing proportions at various times due to the yearly hydrological cycle. The analysis and planning problem is compounded by future development activities which are likely to occur which may reduce the effect of some water quality influences and/or intensify and redistribute others.

Under Section 208 of Public Law 92-500 support is provided for the engineering and planning evaluation of such problems in complex urban and industrial settings. The principal purpose of 208 studies is the local development of cost-effective areawide wastewater management plans for initial and longer term water quality control in a framework suitable for modification in a continuing planning process. A broad scale of water quality control options are to be considered with specific evaluation of the effects of municipal and industrial waste, combined sewer overflow and stormwater runoff, and non-point sources from various land usage categories. The wastewater management plan is to be cost-effective and practical; it must focus on principal problems first, provide a procedure to resolve remaining problems in time; and it should include non-structural controls where possible.

In order to produce a quality plan in a complex 208 area, the array of tasks facing the planner can be formidable. A variety of water quality variables and goals may have to be considered throughout a yearly cycle. Numerous point source wastewater discharges, intermittent sources, and non-point sources may have to be assessed, in many cases with little or no direct data. A multiplicity of techniques are available by which to estimate intermittent and non-point source pollutional discharges, each with specific advantages and disadvantages. Receiving waters can differ markedly in complexity from relatively simple streams and rivers to more complex estuaries, embayments, lakes, and coastal zones, each requiring specific methodologies for analysis. The water quality problems may have differing time and space scales from localized short term bacterial problems, to large spatial scale, seasonal time scales characteristic of eutrophication of receiving waters. A wide variety of engineering and management control options may be available for consideration, each with unique levels of effectiveness, cost, and operational reliability. Therefore, the immediate problem facing the 208 planner is to define the appropriate technical steps and procedures which are to be considered in order to evaluate a multiplicity of problems within the time and resources available and yet which will provide adequate technical information for wastewater management planning.

The initial step in the development of a 208 water quality management plan is associated with preliminary problem identification and assessment. The purpose is to provide the 208 planner in the initial phase of the project as broad a view as possible of the water quality problems, the relative magnitude of various waste sources, and the probable impact of the various sources on water quality. With this perspective, appropriate technical procedures can then be selected to focus on the most important waste sources and water quality problems, and the specific additional data needs can be defined. The more detailed technical procedures which are appropriate for further analysis of those waste load sources which are important in a planning area, are described in Chapter 3 for urban areas, and in Chapter 4 for non-urban areas.

Chapter 2 illustrates the basic data and procedures necessary to perform a preliminary problem assessment. The chapter will provide:

1. An identification and description of the basic data and data sources necessary for the preliminary assessment.

2. Methods to identify and estimate the magnitude of urban and non-urban waste sources on an annual average basis, and during selected critical periods.

3. A method of ranking the importance of the various wastewater sources during different points in the hydrologic cycle by an

analysis of the impact on receiving water quality for a number of key variables.

Chapter 2 is structured into several technical subsections as follows:

Water Quality Problems and Standards - The definition of various water quality problems which may be encountered in local areas and common characteristics of water quality standards which will be relevant.

Characteristics of the Planning Area - A description of the fundamental information necessary for preliminary problem assessment including quantification of point source waste discharges, land use categorization, hydrology and receiving water characteristics.

Water Quality Data Base - A description of the types and sources of water quality data which may be useful to identify water quality problems and determine waste load impacts.

Waste Source Identification and Evaluation - A discussion of the procedures to define or estimate the magnitude of various waste sources including continuous municipal and industrial point sources, intermittent urban loadings from combined sewer overflows and storm drainage, and non-urban non-point source for a variety of land uses.

Receiving Water Analysis - The categories and a discussion of various types of receiving waters including streams and rivers, estuaries, coastal embayments, and lakes and the general characteristics of mathematical water quality modeling techniques useful for determination of water quality impacts.

Illustration and Interpretation of Impact Analysis - A presentation of a simplified technique, by use of an example, to illustrate how existing or potential water quality problems can be identified in streams or rivers and how various waste sources can be ranked in order of importance for specific periods in the hydrologic cycle by determination of water quality impact. The guidance is presented for the proper interpretation of the results of preliminary problem assessments so that appropriate methodologies and procedures can be selected for inclusion in the detailed work plan.

Much of the data and procedures discussed in Chapter 2 are of a general character and will be applicable to many local problem settings. However, in order to further explain the utility of this information, an example problem is included in several of the subsections to illustrate the practical application for a particular problem setting. The importance of this sample problem should not be minimized. It is designed both to instruct and to illustrate the preliminary assessment methodology in sufficient detail to enable the reader to perform the analysis for his specific problem area.

2.2 Water Quality Problems and Standards

The water quality of natural water bodies which receive waste loads from point and non-point sources can be degraded resulting in the impairment of beneficial uses. Point and non-point pollution can interfere with man's uses of the water body for recreation and for water supply. In addition, pollution can upset the natural biology of the system. In general, problems encountered in natural water bodies can be classified into the following major catagories: dissolved oxygen depletion; public health risks, eutrophication, and a general category which combines other water use interferences, including siltation and aesthetic considerations.

2.2.1 Water Quality Problems

2.2.1.1 Dissolved Oxygen Depletion

The quantity of dissolved oxygen present provides an overall measure of the general well-being of a receiving water. Non-polluted streams are characterized by dissolved oxygen levels near the atmospheric saturation concentration and exhibit healthy and diverse biological communities. In areas of a water body adjacent to wastewater outfalls of point and non-point waste discharges, less desirable scavanging organisms increase in number while dissolved oxygen is reduced below saturation or may even be completely exhausted. Sedimentation of the suspended portion of the organic matter results in bottom deposits which continue to degrade and thereby remove dissolved oxygen from the overlying waters. Excessive nutrient enrichment of the waters may result in the development of substantial algal or macrophyte biomass with their associated large diurnal fluctuations in the dissolved oxygen.

These effects of point and non-point sources combine to affect the dissolved oxygen content of the receiving water. Thus, the dissolved oxygen concentration of a water body is a valuable indicator of the state of the receiving water.

2.2.1.2 Public Health

There are many aspects to the relationship between waste loads, receiving water quality and public health considerations. For the purposes of this assessment manual, a limited set of potential contributors to public health problems have been considered.

The presence of infectious organisms and toxic substances creates potential health hazards which can severely limit the intended uses of the receiving water. Potable water supply, recreational uses and shellfish beds are among the beneficial uses which may be affected.

Coliform bacteria are generally used as indicator organisms for the possible presence of pathogens. Total and fecal coliform bacteria are the most commonly used indicators. Of the two indicators, fecal coliforms are the more reliable, since they originate in warm-blooded mammals. While less common in data bases than total coliform counts, fecal coliform data should be used whenever possible.

Although the presence of coliforms in receiving waters is the dominant public health concern in the preliminary analysis, it should also be recognized that heavy metals, pesticides and refractory materials may enter the receiving water from municipal and industrial pollution sources or from urban runoff. Pesticides may also originate from application to crops in agricultural areas. These materials may accumulate to harmful levels in the food chain, and should be considered in the context of areawide water quality analyses.

2.2.1.3 Eutrophication

The combination of excessive nutrients, suitable water temperature and adequate sunlight may cause excessive production of algae and higher plant life in natural waters. Problems associated with excessive algal growth may include objectionable taste and odors in water supplies and interference with water treatment operations. In addition, excessive growth of water weeds may reduce the hydraulic capacity of natural conduits, cause flooding of lowlands, and generally obstruct desired uses. They may interfere with recreation by creating conditions which interfere with the attractiveness or usefulness of a water body. As pointed out previously, large diurnal fluctuations in dissolved oxygen may occur as the photosynthetic or respiratory activity dominates.

2.2.1.4 Other Water Use Interferences

The more important contaminants included in this category are suspended, floatable, and dissolved solids and solid particulates whose presence may be harmful in themselves or serve as a transport mechanism for sorbed pollutants. Suspended solids borne by the water may settle out in impoundments and reduce storage capacity. Excessive levels may cause destruction of fish life or benthic organisms. Stream flow used for irrigation may build up high concentrations of total dissolved solids. This results in an economic burden on downstream agricultural areas where crop yields may be severely reduced. Finally, floatable solids are undesirable in any natural watercourse.

In addition to the above, in some situations other parameters such as temperature, pH, oil and grease, and specific ions in excessive concentration sodium, chloride, etc., may also have to be considered.

For this preliminary analysis, the suspended solids are chosen since waste source and receiving water data are generally available and the analysis framework is simple. Total dissolved solids analyses are more complex and are treated in a subsequent chapter.

2.2.2 Water Quality Standards

Both the water quality constituents regulated by the standards and the allowable concentration of those constituents are not the same from state to state. In addition, some local agencies may impose water quality regulations which are more stringent than those imposed by the State governments. However, the physical properties and chemical parameters regulated by water quality standards are established for their relationship to the well-being of the water body and the beneficial uses which can be derived from its use.

The water quality standards are obtained at the start of the planning study directly from the state agencies. Usually, the state agency publishes a document which defines the water quality criteria and classifies each surface water body.

After the water quality classification for each water body in the 208 study area is obtained from the State, the classifications for the particular water bodies can then be superimposed on a study area map. For example, the 97 miles of the Black River in New York State are shown in Figure 2-1 along with the water quality classifications. Figure 2-1 shows that the Black River and Black River Bay are divided into 6 water quality segments. The water quality classifications that apply to these segments are A, C, C-trout, and D. Water usage in these stream reaches is intended for water supply (Class A), fishing (Class C), fishing-trout (Class C-trout), and secondary contact recreation (Class D).

Quantitative standards for these classifications are given for pH, dissolved oxygen, dissolved solids and coliform bacteria. The standards are listed in Table 2-1 for Class A, B, C and D waters. In addition to the above water quality standards, New York State policy for the Lake Ontario basin requires wastewater dischargers of 1.0 MGD or larger to reduce effluent phosphorus to 1.0 mg/l or less.

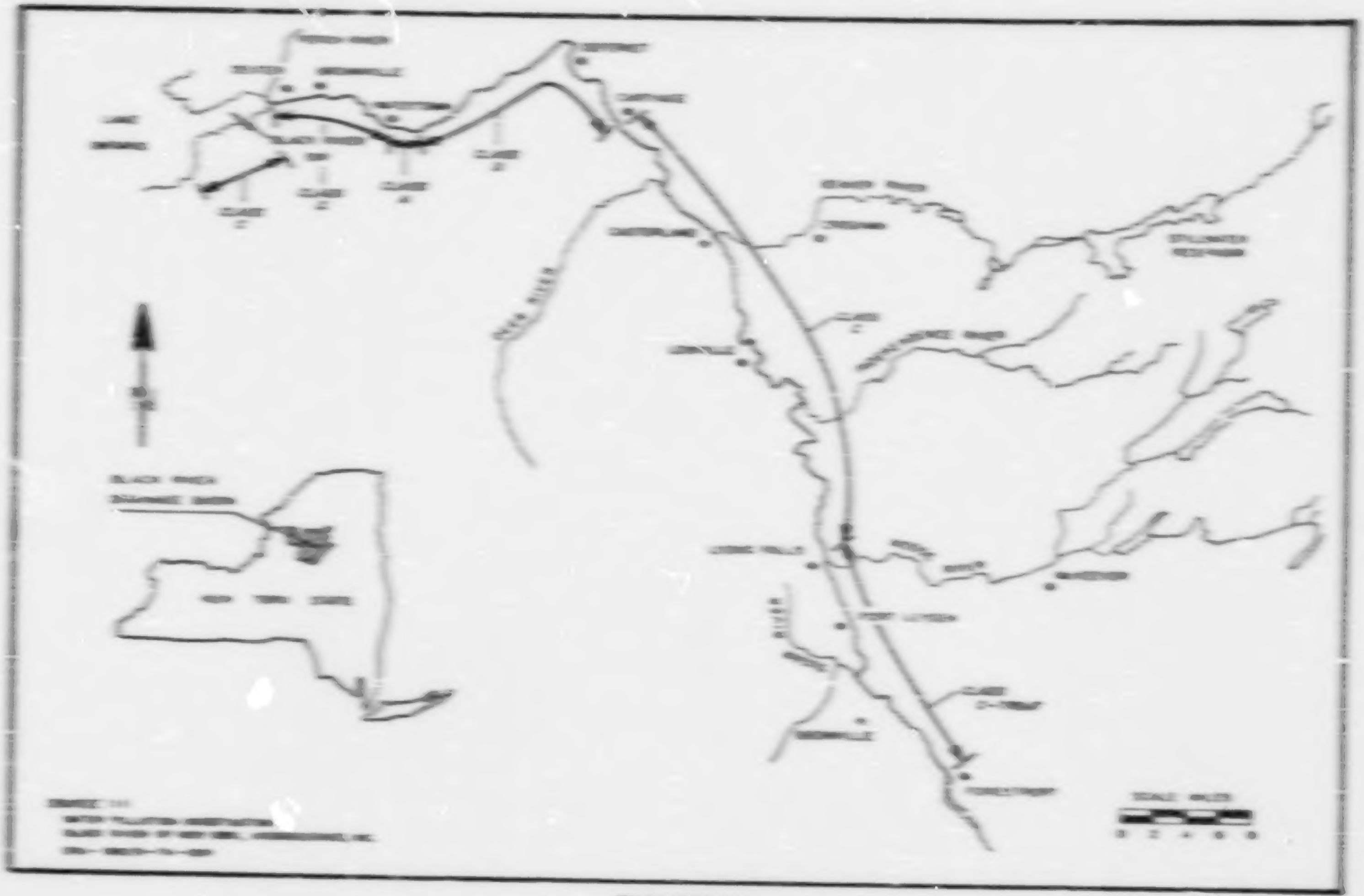

FIGURE 2-1
WATER QUALITY CLASSIFICATIONS OF THE BLACK RIVER

TABLE 2-1

NEW YORK STATE WATER QUALITY STANDARDS

Constituent	Class A	Class B	Class C	Class D
pH	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.0 - 9.5
Dissolved Oxygen - mg/l (Minimum Daily Avg)	5.0	5.0	5.0 6.0 (Trout)	Never less than 3.0
Dissolved Solids - mg/l (Maximum)	500	500	500	-
Total Coliform - No./100 ml	Monthly Median 5,000	Monthly Median 2,400	Monthly Geom. Mean - 10,000	-
Fecal Coliform - No./100 ml	Monthly Geom. Mean - 200	Monthly Geom. Mean - 200	Monthly Geom. Mean - 2,000	-
Phenolic Compounds - mg/l	0.005	-	-	-

Source: (1)

The standards for dissolved oxygen and coliform bacteria presented in Table 2-1 are for average conditions. For dissolved oxygen, the minimum daily average is reported. For the A, B and C classifications the specifications further stipulate that at no time shall the dissolved oxygen concentration be less than 4.0 mg/l for non-trout waters and no less than 5.0 mg/l for trout waters. In addition to specifying average conditions, the total and fecal coliform standards also include the minimum number of analyses required plus the maximum total coliform counts permitted in 20 percent of the samples.

The water quality classifications and standards can also be shown on the spatial water quality plots to assist in data interpretation. Figure 2-2 shows the spacial dissolved oxygen data observed on August 14, 1973 in the Black River and two of its tributaries. The dissolved oxygen standards are shown on each of the water quality plots. The extent of the six water quality segments and the dissolved oxygen standard for each segment can be readily compared to the observed data in this figure. It is evident from Figure 2-2, that during August of 1973, the dissolved oxygen concentrations were depressed below the standards for 25 miles of the Black River. In the two tributaries, the observed dissolved oxygen levels were well above the dissolved oxygen standards. Similar plots for the other water quality substances showed that acceptable levels of the constituents were present in August.

Figure 2-3, is an example for the Jordan River in Utah, which indicates a violation of the total coliform water quality standard. These data are average values of all the STORET summer total coliform data. The total coliform standard is 5,000/100 ml for the entire 52 miles of the river. The comparison of the observed data to the total coliform standard shows that the coliform standard is violated on an average basis for more than 30 miles of the Jordan River.

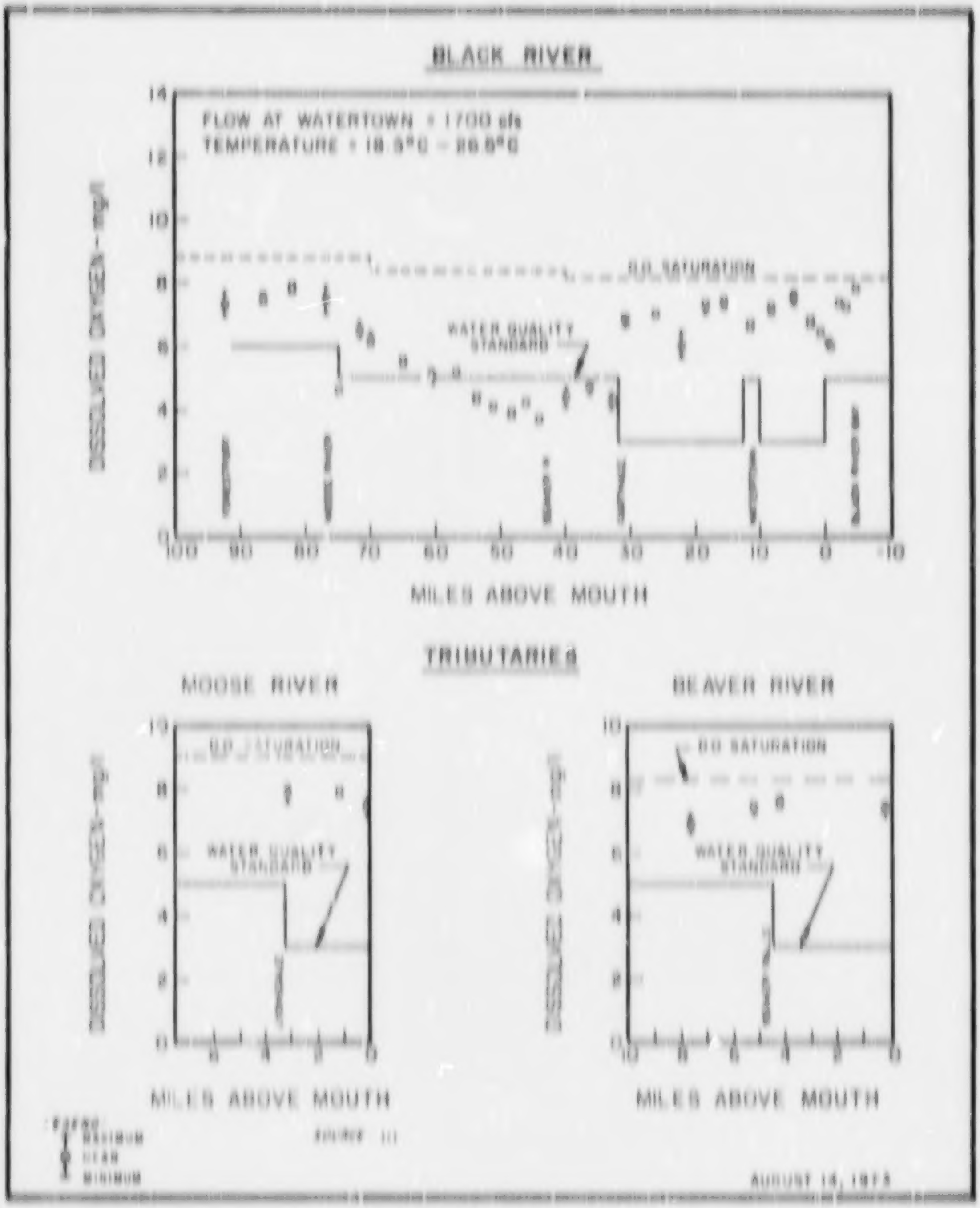

FIGURE 2-2
DISSOLVED OXYGEN DATA AND STANDARDS
(BLACK RIVER, N.Y.)

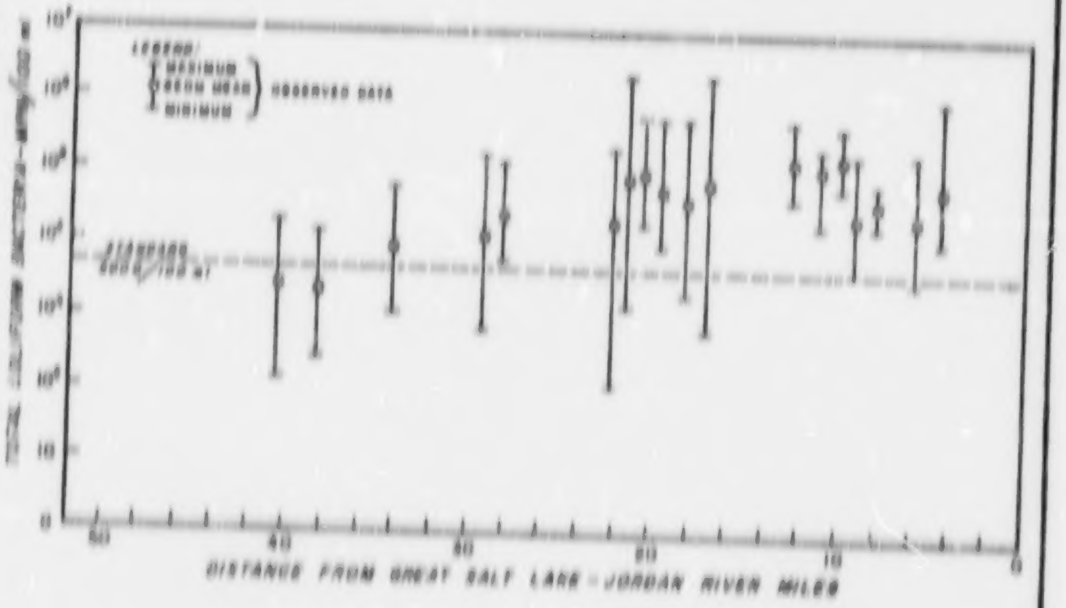

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FIGURE 2-3
INSTREAM TOTAL COLIFORM DATA
(JORDAN RIVER, UTAH)

2.3 Characteristics of the Planning Area

2.3.1 General Description

The 208 planning area study limits are defined at the start of the project and generally conform to political boundaries. However, in the evaluation of all factors that affect water quality within the designated 208 planning area, it may be necessary to look beyond the political boundaries. For example, water quality in rivers is directly related to land use in the entire river basin which might not be entirely incorporated within the designated 208 planning area. In estuaries, water quality at a particular location is also affected by conditions a considerable distance downstream because of tidally induced mixing. Therefore, wastewater loads downstream of a 208 study area might significantly affect upstream water quality.

In the discussions which follow, Figure 2-4 presents a map of the hypothetical 208 planning area for the illustrative problem. The 208 study area boundary is indicated by the dashed line and the drainage basin boundary is defined by the solid line. As shown, the section of the South River within the 208 study area receives runoff from land outside the 208 boundaries. At the upstream end of the study area, near Route 80, the South River water quality is related to point and non-point source loads that enter the river between the headwaters and Route 80. From this example, it can be seen that the general description of the study area should be expanded beyond the limits defined by the designated 208 planning area. It should be emphasized that the only purpose for expanding the extent of the original study area is to better understand those factors that influence water quality within the original designated 208 area.

2.3.2 Land Use

The type and quantity of non-point source loads depend on land use. Land use can be divided into urban and non-urban areas. Generally, the urban land uses are subdivided into residential, industrial, commercial and open areas. The non-urban land uses are divided into areas of

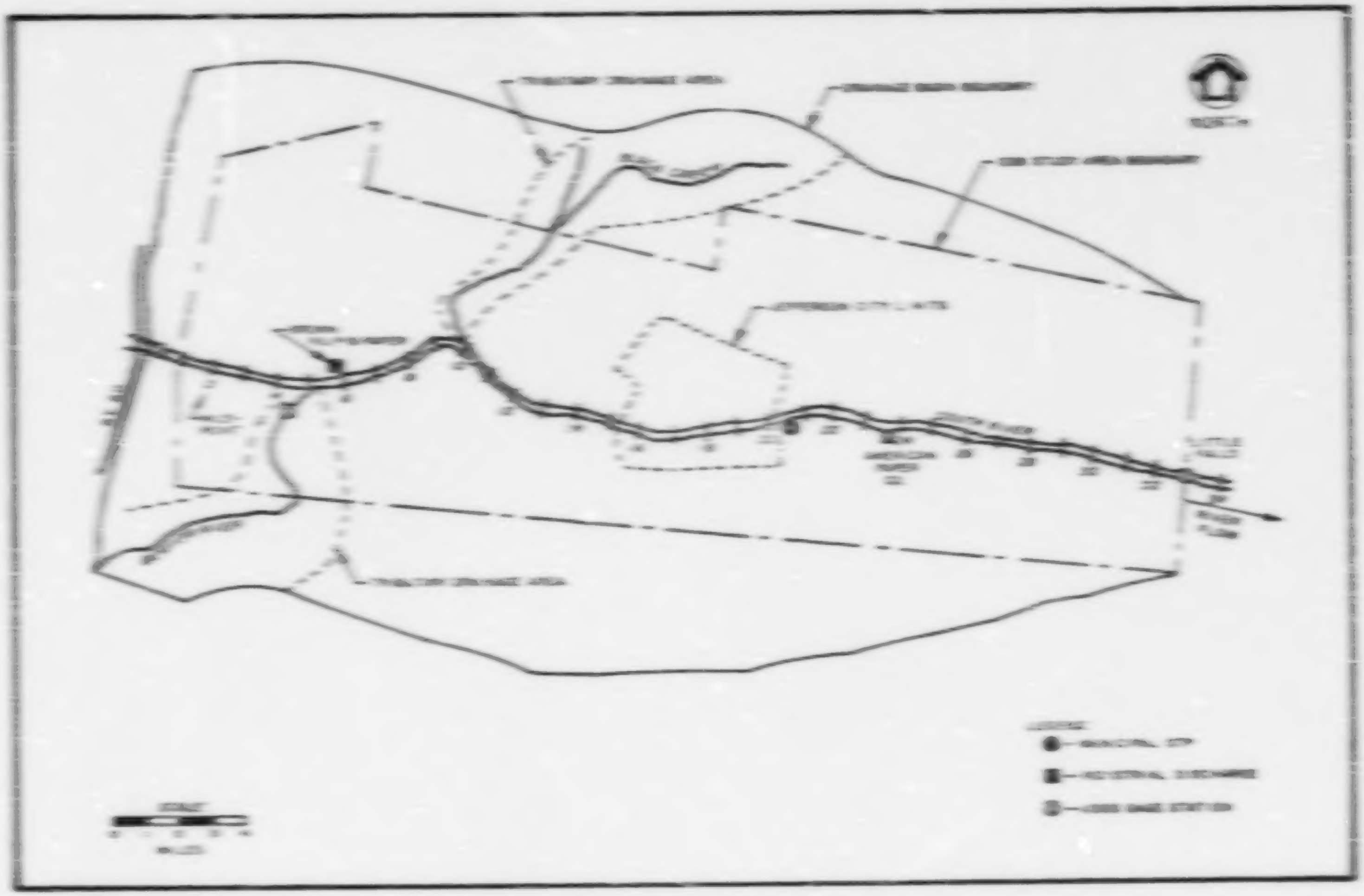


FIGURE 2-4

MAP OF HYPOTHETICAL PLANNING AREA

SOUTH RIVER, USA

agriculture, forest, silviculture, mining, and feedlots. In addition, construction and highway activities in both the urban and non-urban areas generate non-point source (NPS) loads. Residual management practices, such as waste disposal in sanitary landfills, may also be substantial sources of non-point source pollution. In addition to classifying a general land use pattern within the study area, further details concerning land use may be required for the estimation of non-point source loads. For example, soil type and other factors affecting erosion are used in some empirical formulas to compute non-point source loads from open areas. In urban areas, population density can be used in some estimating techniques for calculating storm runoff. In addition, maps detailing pervious and impervious areas, together with handbook relationships can also be useful.

If land use management controls are not practiced, each land use activity has the potential of adding to the degradation of the local and distant waterways. In order to estimate the NPS loads for each major constituent, it is first necessary to determine the distribution of the land use activities in the study area and the areal extent of each land use activity.

Land use data in any 208 study area is available from many sources. These are described in Appendix C of this manual, Land Use Data Collection and Analysis. In general, however, the list would include:

a. Local planning agencies
b. State planning agencies
c. Standard Metropolitan Statistical Area (SMSA) Data
d. H.U.D.
e. Previous basin plans or facilities plans
f. Soil Conservation Service

The calculation of NPS loadings from land use activity and population density will be discussed in more detail in Chapters 3 and 4. As a first step in preliminary problem identification, the definition of general land use patterns is sufficient.

Figure 2-5 presents the general land use pattern for the hypothetical South River 208 study area. As indicated, most of the land bordering the river is agricultural. Forested lands are located at the northern boundary of the drainage area and at the southeast and southwest corners. The urban areas, Jefferson City, is located in the middle of the study area.

The drainage area distribution by land use at five points along the South River is summarized in Table 2-2 and graphically presented in Figure 2-6. At Milepoint 0, the Route 80 Bridge, the drainage area is 500 square miles. For the 208 study, the land use of the upstream point and non-point source loads is defined by water quality measurements at Milepoint 0. At Milepoint 5, the runoff from the Beaver River drainage basin (250 square miles) enters the South River. As with the upstream drainage area, the impact of loads within the Beaver River basin is defined from water quality measurements at the mouth of Beaver River. The increase in drainage area between Milepoints 5 and 33 is agriculture plus forest land with 20 square miles of urban drainage area between Milepoints 15 and 20. Since the flow in Block Creek is minor, the drainage area of the creek is included in the analysis as part of the NPS forest area.

The graphical presentation of the drainage area distribution clearly demonstrates that areas outside of the 208 study area boundaries may significantly influence water quality within the 208 study area. Most of the drainage basin of the Beaver River and all of the upstream drainage area are outside of the 208 study area yet they compose approximately 60% of the total drainage area at Milepoint 33. Figure 206 also graphically shows that the urban area is a relatively small component of the total drainage area.

An analysis of the land use similar to the above should be performed by the 208 planning agency.

2.3.3 Hydrological Data Bases

The local hydrological cycle affects water quality in the drainage basin. The runoff, which depends on the geophysical characteristics of

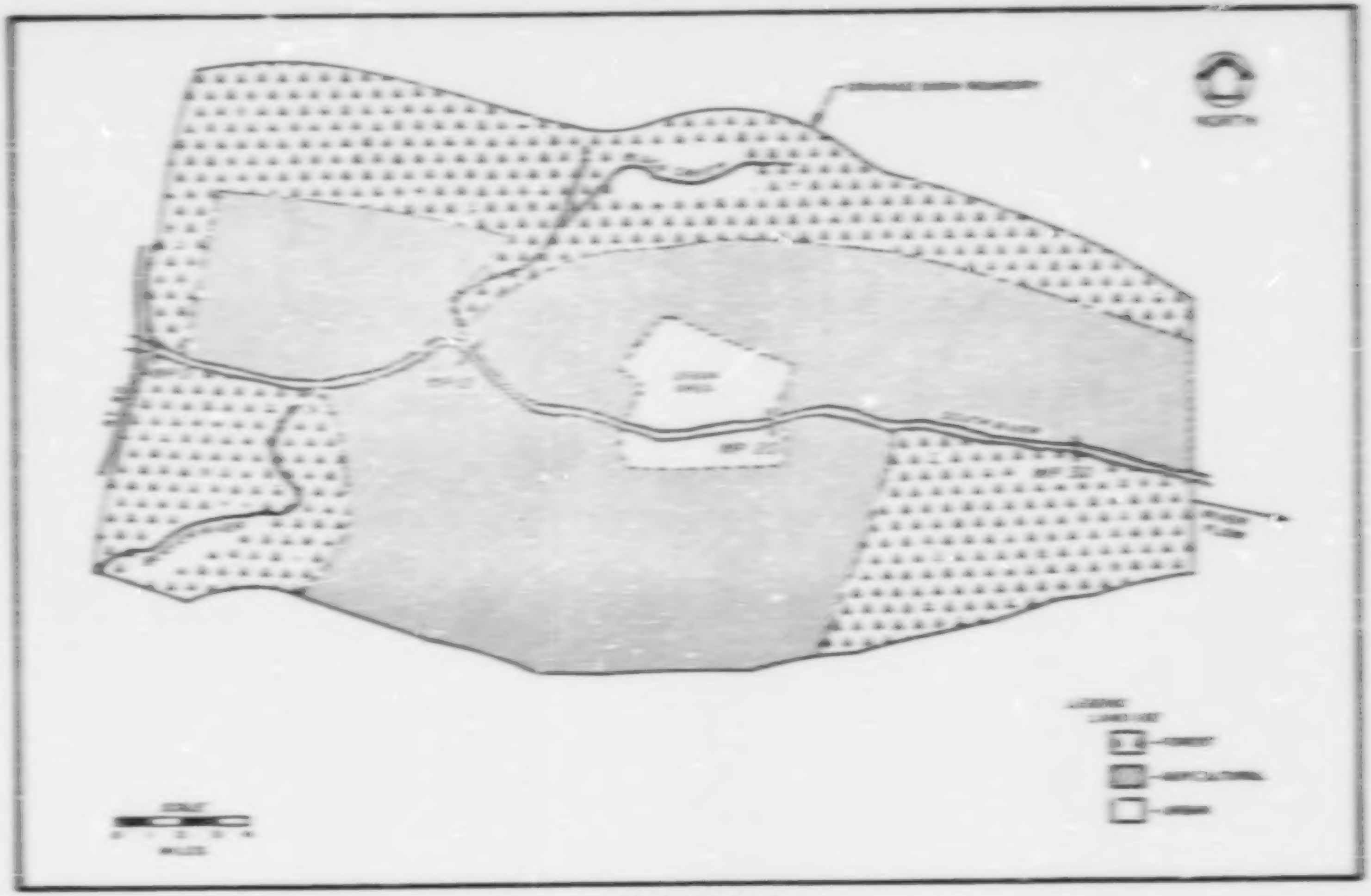


FIGURE 2-5
SIMPLIFIED LAND USE PATTERNS
(SOUTH RIVER, U.S.A.)
HYPOTHETICAL EXAMPLE

TABLE 2-2

DRAINAGE AREA DISTRIBUTION BY LAND USE
(SQUARE MILES)
FOR SOUTH RIVER HYPOTHETICAL EXAMPLE

Milepoint	Upstream	Agriculture	Forest	Tributary	Urban
0	500	0	0	0	0
5	500	30	40	250	0
15	500	160	65	250	0
20	500	210	75	250	20
33	500	280	150	250	20

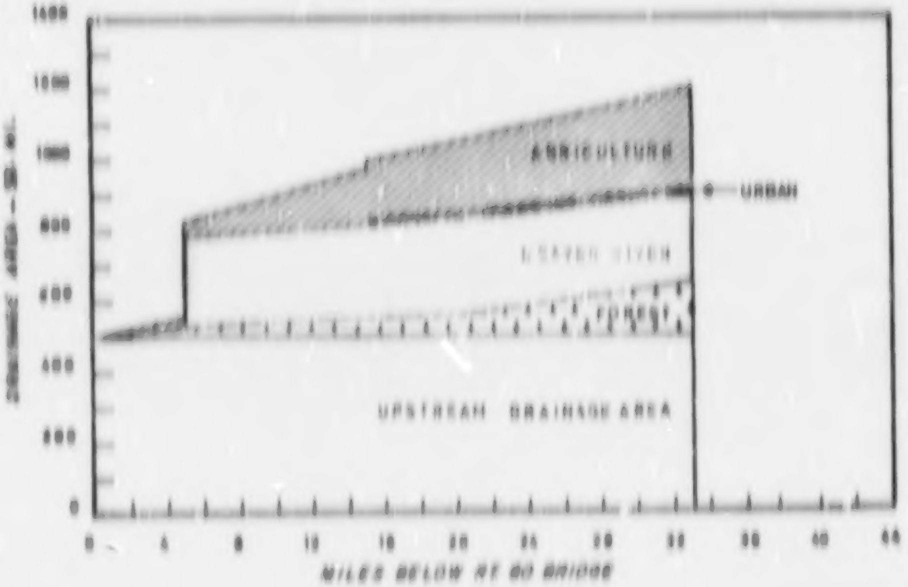


FIGURE 2-6
DRAINAGE AREA DISTRIBUTION BY LAND USE
(SOUTH RIVER, U.S.A.)
HYPOTHETICAL EXAMPLE

the drainage basin, the land uses and control practices, and the amount, frequency, and intensity of rainfall, may improve or degrade water quality.

In order to assess the impact of point and NPS loads on a water body, it is important to know the stream flow and the stream flow patterns. In any one drainage basin, stream flow will vary over the year depending on the rainfall and/or snowmelt. Figure 2-7 shows average monthly distribution of runoff as percent of total runoff over the year for 16 river basins in the country. It is interesting to note that in the Kissimmee River Basin in Florida, the stream flow is relatively constant over the year. However, in the Yellowstone River Basin, Montana, the maximum monthly stream flows are about 10 times as great as the minimum monthly stream flows. In addition, the Yellowstone River has a minimum stream flow which occurs in the month of February by contrast to the majority of streams in the country, in which low flow occurs in late summer or early fall.

Because of the variation in runoff across the country, it is necessary to collect the site specific stream flow data. In general, there will be one or more flow gaging stations within the 208 planning boundaries. These records are published as annual surface water reports by the U.S.G.S.. Table 2-3(a) is a sample data sheet from the U.S.G.S. surface water records. The data sheet summarizes drainage area, daily flows for the year, monthly average flows, and monthly maximum and minimum flows at a gaging station.

For the preliminary analysis, stream flow data is reduced to monthly average flows for the number of years of record available. The annual average stream flow is calculated in addition to the minimum average 7-consecutive-day, one-in-ten-year low flow. All tributaries of significant size are located with respect to the main channel. If flow information is not available for the tributaries, then estimates of the annual average flow and the seasonal patterns are made by assigning the same runoff yield (cfs/sq. mile) as the major drainage basin as discussed subsequently. After the stream flow data in the main stem and the

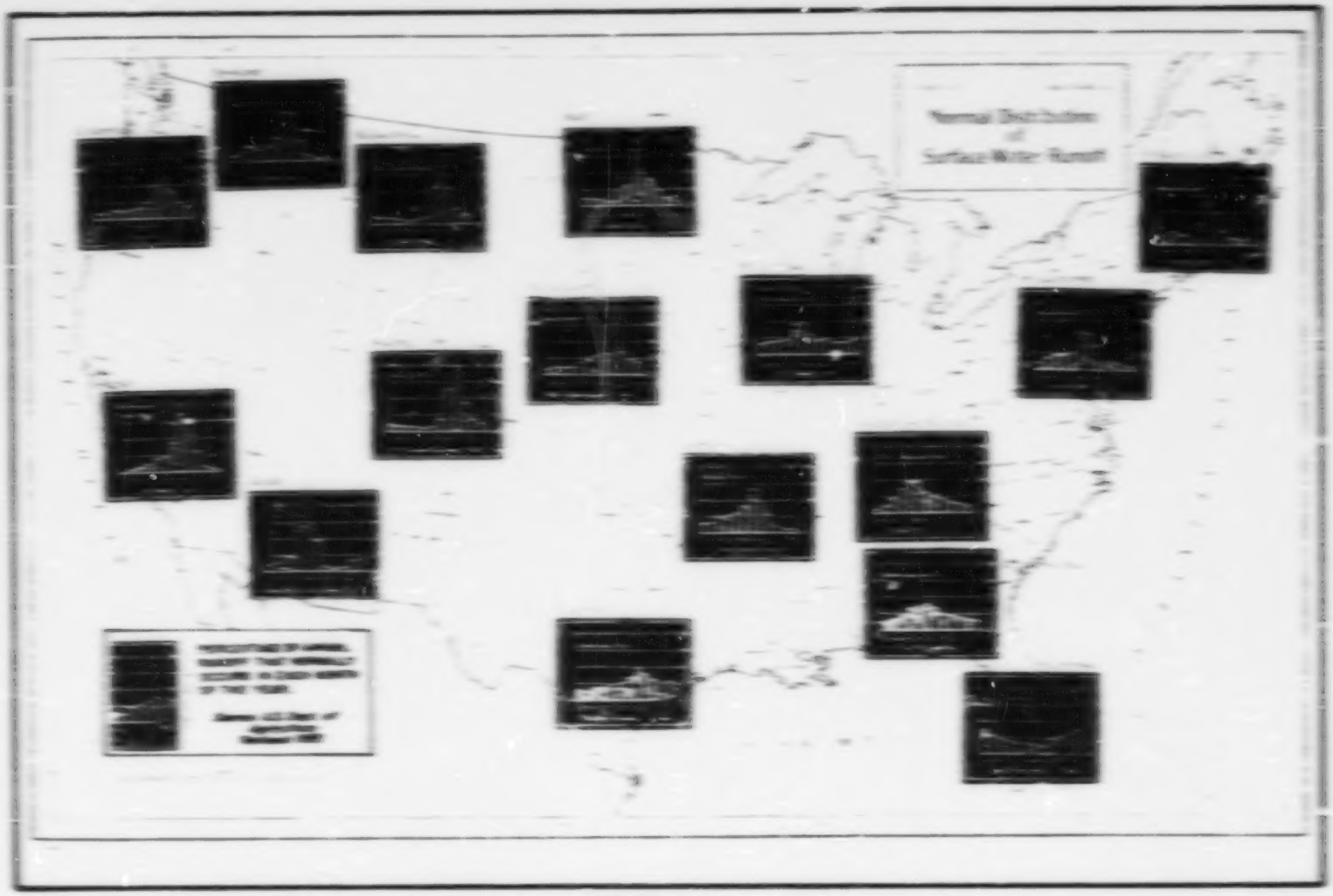

Normal Distribution
of
Surface-Water Runoff
PERCENTAGE OF NORMAL RUNOFF THAT NORMALLY OCCURS IN EACH MONTH OF THE YEAR.

FIGURE 2-7

NORMAL DISTRIBUTION OF SURFACE-WATER RUNOFF

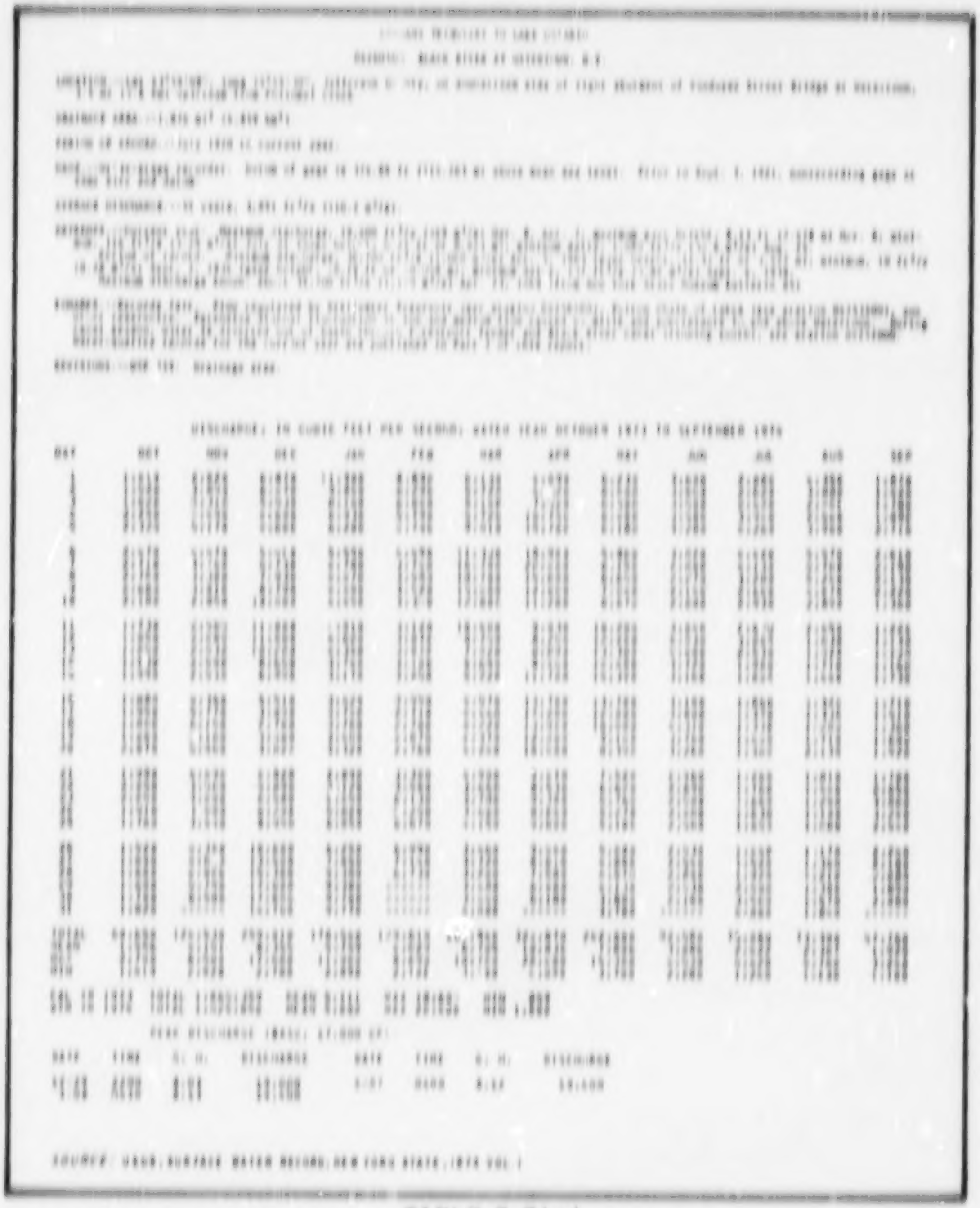


TABLE 2-3(a)
SAMPLE U.S.G.S SURFACE WATER RECORD DATA SHEET

tributaries are established, these data are plotted with respect to river miles. This information will be used in the preliminary water quality assessment to estimate the dilution and transport of the wastewaters which enter the stream.

For example, the hypothetical South River average monthly flows are plotted in Figure 2-8 for gaging stations at the upstream and the downstream end of the study area. The spatial increase in flow between the Route #[illegible] Bridge gage and Little Falls gage is represented by the difference between the solid and dashed lines in the hydrograph. The freshwater flow originating in the Beaver River drainage basin is also shown in Figure 2-8.

The spatial distribution of the freshwater flow in the South River drainage basin is presented in Figure 2-9. The average annual, summer and low flow profiles are also plotted in this figure. At Milepoints 5 and 10, the flow is incremented by the Beaver River and Black Creek, respectively. The linear increase in flow between Milepoints 0.0 and 35 is due to the surface and groundwater return flows along the length of the river. The above example illustrates the presentation and reduction of the hydrological data for 208 planning areas.

In addition to computing flow statistics and spatial flow distributions, the total stream flow can be broken down into its components which are the flow inputs from groundwater, tributaries, surface returns, continuous point sources such as wastewater treatment plants, and sewer wet and dry weather overflows. Tributary flow data will generally be available from the U.S.G.S. or it can be generated from local runoff rates and the tributary drainage area as subsequently discussed. Wastewater treatment plant flows and other continuous point sources are available from the treatment plant records, the 201 and 303(e) basin plans and the city drawings. An average estimate of the groundwater input can be obtained from the annual hydrograph. For example, Figure 2-10 shows the hydrograph over 4 years of record for Big Cottonwood Creek in Salt Lake County, Utah. On the hydrograph, the groundwater flow is estimated as the flow occurring during periods of little rainfall or snowmelt. The surface

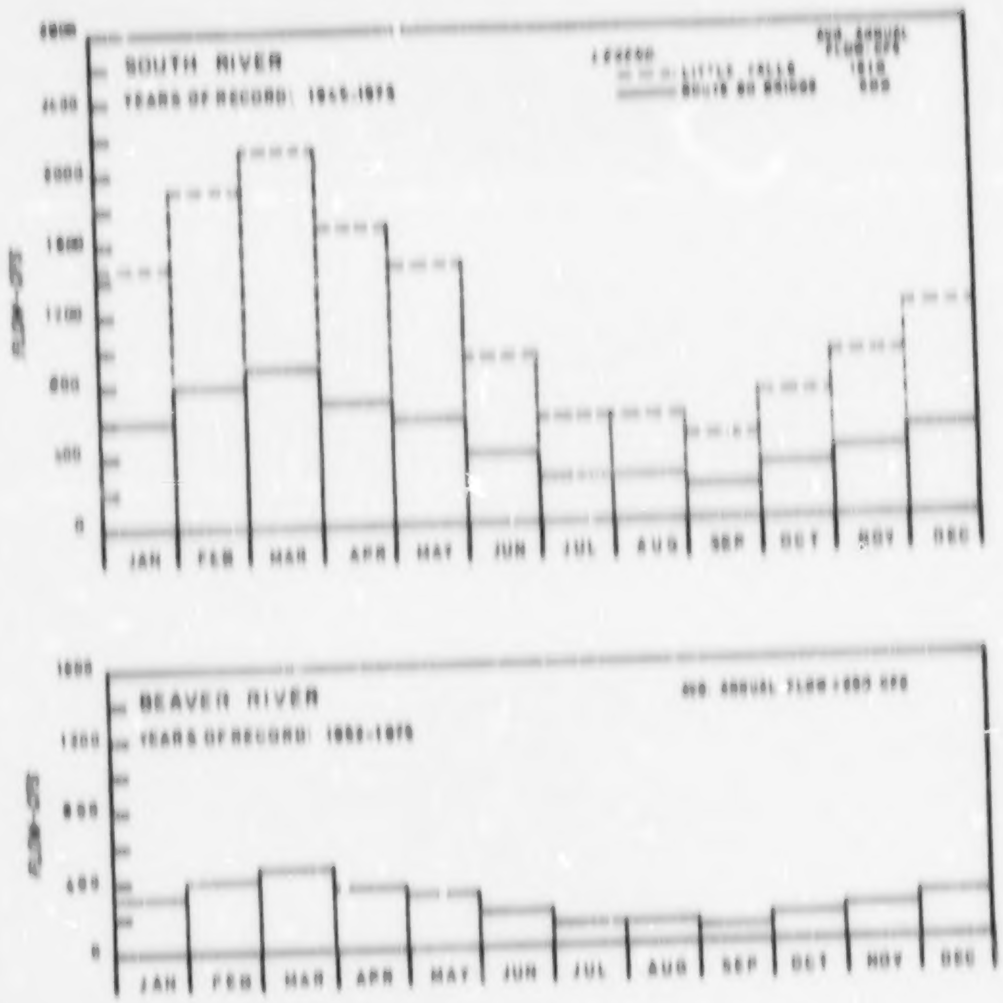


FIGURE 2-8
AVERAGE MONTHLY FLOW, DATA
(HYPOTHETICAL SOUTH AND BEAVER RIVER, U.S.A.)

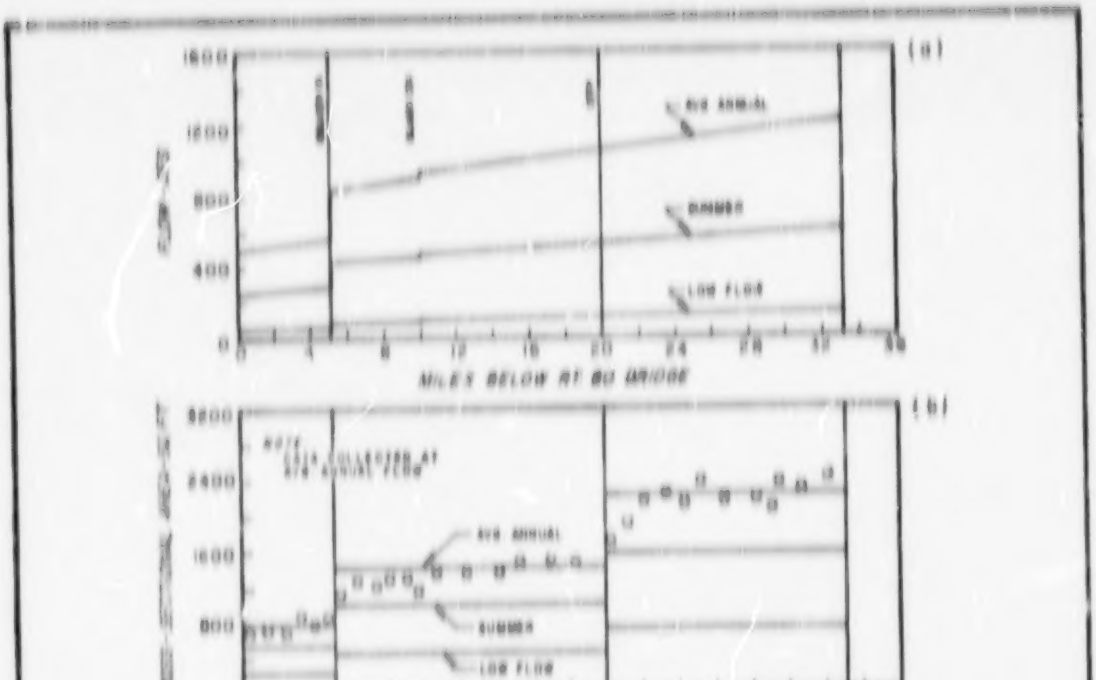
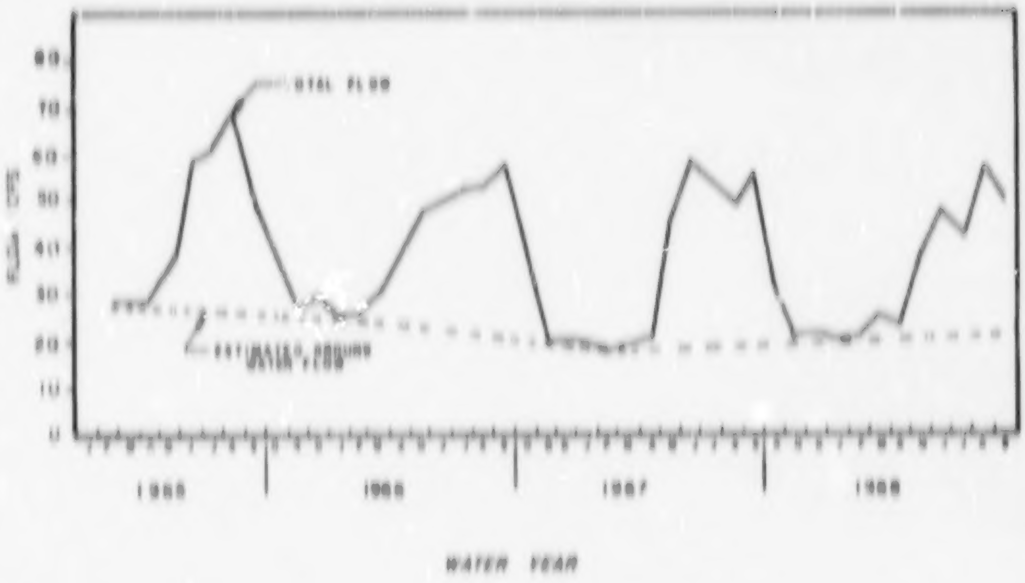


FIGURE 2-9
RIVER FLOW, GEOMETRY AND TIME OF TRAVEL DATA
(HYPOTHETICAL SOUTH RIVER, USA.)



SOURCE (8)

FIGURE 2-10
TOTAL FLOW AND ESTIMATED GROUND WATER FLOW
BIG COTTONWOOD CREEK, UTAH

runoff is the remaining unknown and it can be assigned as the difference between the total flow and the known components.

The components of the flow at many locations in the river can be assembled into a spatial flow distribution. In Figure 2-11, the component flows are developed for the Jordan River during a typical summer flow period. The flow in the Jordan River is a combination Utah Lake water, groundwater, tributary flow, agricultural surface returns, and wastewater flow.

For some streams U.S.G.S. gaging records do not exist. In order to determine the stream flow for a refined and definitive impact analysis, stream flow monitoring may have to be instituted. However, crude estimates of average stream flows can be made in order to continue the preliminary impact analysis. Average runoff yields can be used and applied to the specific drainage areas to estimate average stream flows. Figure 2-12(a) shows the average annual runoff yield distribution for the entire country. Preliminary high and low flow runoff estimates can be made with the use of the monthly runoff distribution presented in Figure 2-7 and Figure 2-12(a).

In tidal rivers and estuaries, the freshwater flow at any location can be estimated by adding the freshwater flows orginating from tributaries, municipal and industrial point sources, surface inflow and groundwater inflow. The freshwater flow in tidal rivers and estuaries produces a freshwater velocity as it does in streams. However, the freshwater velocity in tidal waters is generally small compared to the tidal velocity. Tidal velocity information is available from the National Ocean Survey which is a branch of the National Oceanic and Atmospheric Administration. Tidal velocity information is used to calculate the atmospheric reaeration coefficient and the average tidal translation which will be important parts of the water quality impact analysis (Chapter 5).

2.3.4 Topography

The topography of the study area is the slope and elevation of the land. This information is readily obtained from maps published by the U.S.G.S.. For local areas, city and state agencies can provide additional maps. In addition to providing an overall representation of the land contours within the study area, topographical maps may also be used to define the

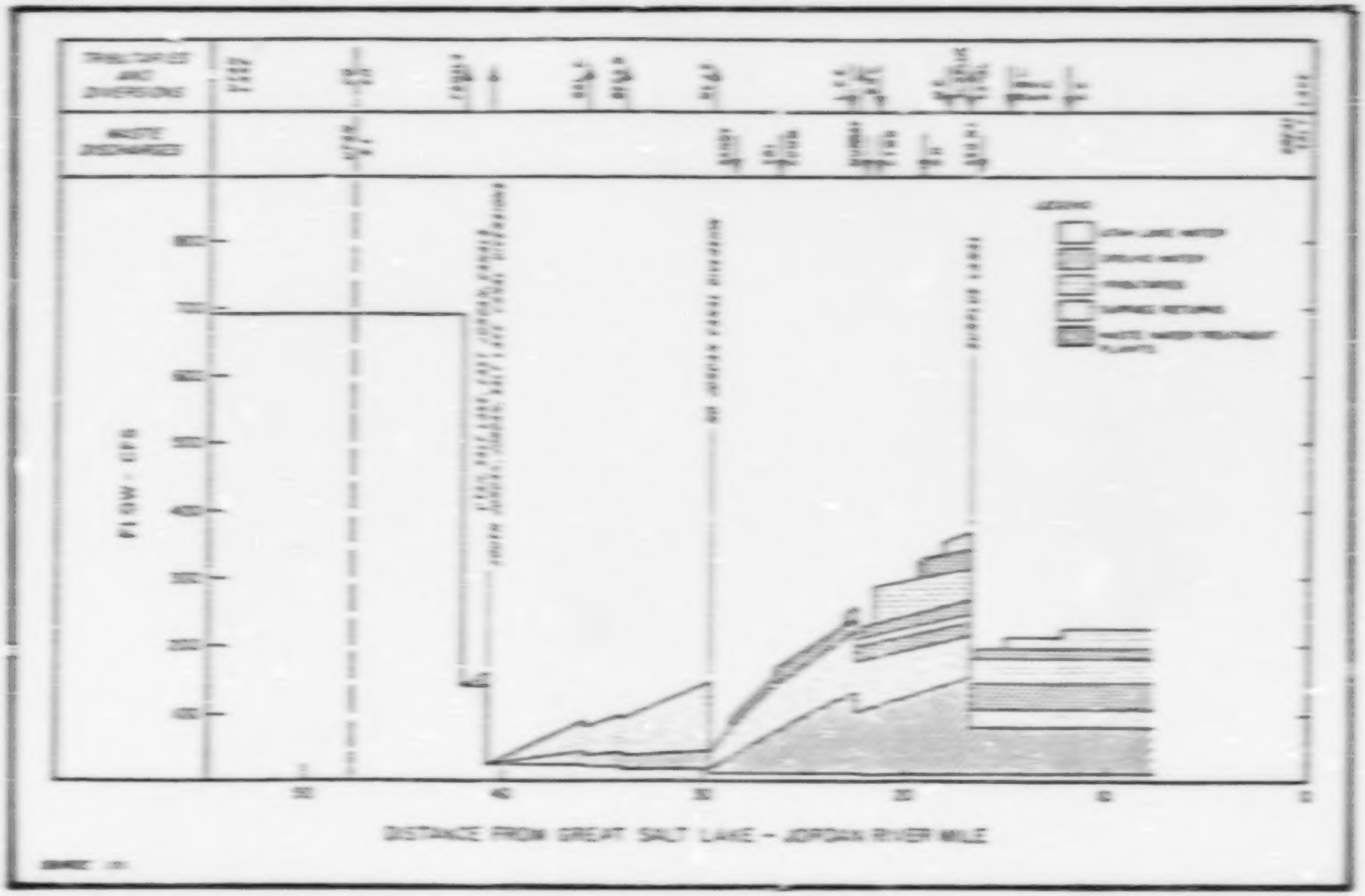
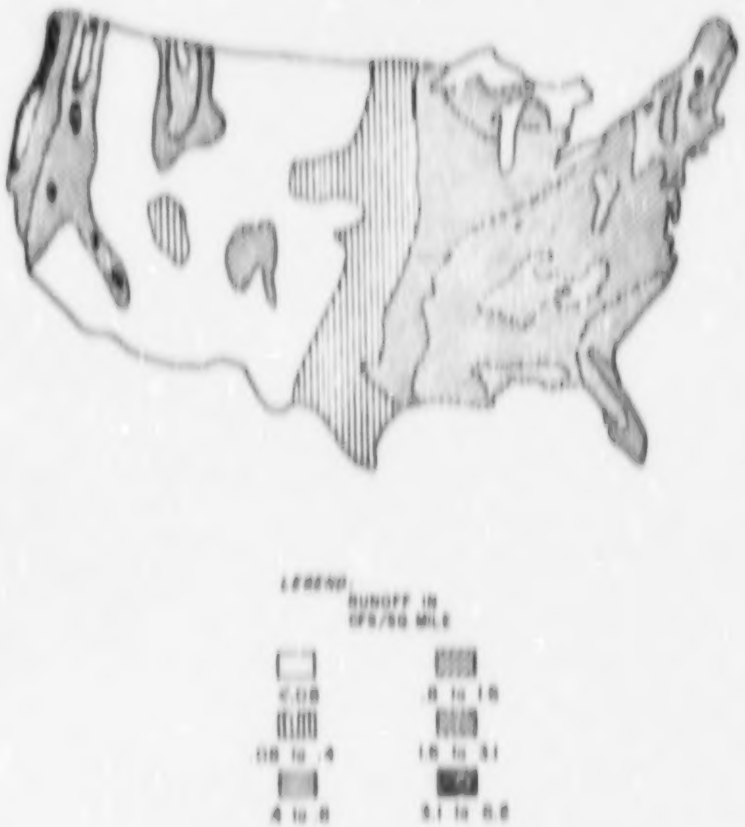


FIGURE 2-11
COMPONENTS OF A TYPICAL SUMMER FLOW DISTRIBUTION
(JORDAN RIVER, UTAH)



REF. U.S. DEPT. OF INTERIOR

FIGURE 2-12(a)

ANNUAL RUNOFF YIELDS IN THE COTERMINOUS UNITED STATES drainage area of the entire river basin and also the drainage area of major tributaries. For many rivers, the U.S.G.S. reports the drainage area with their annual flow record publications. In the preliminary analysis, drainage area and runoff information can be used to estimate river flows as discussed subsequently.

Topographic data can also provide insight into the quantity and quality of surface runoff within the study area. Areas of high elevation generally have more rainfall than valley regions, due to orographic effects on the windward side. Hence, more rainfall can be expected from mountainous areas of the study area. Land slope also affects the relationship between runoff and rainfall. Steeper slopes produce more runoff per unit intensity of rainfall. Land areas with steeper slopes also have higher erosion rates and, consequently, higher suspended solids and associated pollutants in surface runoff. Appendix C provides a detailed discussion of the available maps and other information.

2.3.5 Geomorphological Information

Stream channel depth and cross-sectional area data are required for the main receiving water body. This information may be available from the U.S.G.S., State agencies, EPA, Coast and Geodetic Survey or previous studies. If no depth or cross-sectional area data are available, it is usually necessary to make in-stream measurements during the 208 study.

In some study areas, time of passage (travel time) information will be available from the U.S.G.S. or from previous studies. Time of passage data along with stream cross-sectional area and depth data is used in the impact analysis for computing average velocity. The time of passage data and the channel cross-sectional area data should be related to the stream's flow. If enough data are not available to establish these relationships, then equations (2-1) to (2-4) can be used to estimate the changes in river characteristics for a different flow regime. They relate the changes in these characteristics to changes in the flow ratio to a *power* less than one:

Reference: (6)

$$\frac{A_2}{A_1} = \left(\frac{Q_2}{Q_1}\right)^{0.5} \qquad (2\text{-}1)$$

$$\frac{H_2}{H_1} = \left(\frac{Q_2}{Q_1}\right)^{0.4} \qquad (2\text{-}2)$$

$$\frac{V_2}{V_1} = \left(\frac{Q_2}{Q_1}\right)^{0.5} \qquad (2\text{-}3)$$

$$\frac{\text{Time of Travel}_2}{\text{Time of Travel}_1} = \left(\frac{Q_2}{Q_1}\right)^{-0.5} \qquad (2\text{-}4)$$

where Q is the flow rate, A is the cross-sectional area, H is the mean stream depth, and V is the average velocity.

It should be recognized that these relationships are true only for free flowing rivers and that the exponents may vary by 50% for any river. Therefore, if possible, the exponents should be established from available data. However, if there is not enough information available to establish the exponents, then equations (2-1) to (2-4) can be used with caution.

The hypothetical South River cross-sectional area and depth data are presented in Figures 2-9, plots (b) and (c). These data were collected at a river flow approximately equal to the annual average flow. Area and depth measurements for this flow regime are available for every mile along the watercourse.

For ease of calculations, the river was divided into 3 areas of approximate equal physical characteristics. Between Milepoints 0 and 5 the river was characterized as having a cross-sectional area of 800 sq. ft. and a depth of 3 ft. For Milepoints 5 to 20 and 20 to 33, the cross-sectional area averaged 1,400 sq. ft. and 2,200 sq. ft. while the depth average 5 ft. and 6 ft. respectively. Equations (2-1) and (2-2) were used to determine the cross-sectional areas and depths of the three river segments at summer flow and low flow. Table 2-3(b) summarizes the hypothetical geometry for the South River example.

Figure 2-9, plot (d), presents the time of travel information for the South River between the Route 80 Bridge and Little Falls. The time of passage through the system is calculated from the freshwater flow and the cross-sectional area in each river section: velocity = flow/cross-sectional area and Travel Time = distance/velocity.

2.3.6 Climatological Data

Climatological data is available for many locations throughout the country. The data is available from the National Oceanic and Atmospheric Administration which is a section of the U.S. Department of Commerce. Climatological data sheets contain information on air temperature, precipitation, wind, sunshine and sky cover, visibility and humidity. An example is shown in Figure 2-12(b). All data are daily data except precipitation which are hourly data. Data are compiled from records on file at the National Weather Records Center, Asheville, North Carolina and are available from the U.S. Printing Office, Washington, D.C. For the preliminary impact analysis, precipitation data (water equivalents) should be reduced to average monthly and annual average rainfall data. These data are used subsequently to provide preliminary estimates of the combined and separate sewer overflow mass discharge rates. Rainfall data are used in Chapters 3 and 4 to provide more refined mass discharge estimates.

2.4 Water Quality Data Base

River water quality data are necessary for a preliminary problem identification and also for the preliminary impact analysis. A review of existing river water quality data might reveal existing water quality problems. If existing water quality data are not sufficient in spatial and temporal detail, existing water quality problems may not be obvious. For example, dry weather water quality data does not identify the direct impact of stormwater runoff during the storm event.

TABLE 2-3(b)

HYPOTHETICAL SOUTH RIVER

RIVER FLOW, GEOMETRY, AND TRAVEL TIME (AVERAGE ANNUAL, SUMMER, AND LOW FLOW)

Milepoint	Flow Condition	Flow cfs	Cross-Sectional[a] Area sq.ft.	Depth[b] ft.	Travel Time[c] days
0 - 5	Avg. Annual	535	800	3.0	0.46
	Summer	268	566	2.3	0.65
	Low Flow	54	253	1.2	1.45
5 - 20	Avg. Annual	943	1,400	5.0	1.39
	Summer	472	990	3.8	1.97
	Low Flow	95	443	2.0	4.40
20 - 33	Avg. Annual	1,158	2,200	6.0	1.56
	Summer	569	1,555	4.5	2.20
	Low Flow	114	696	2.4	4.93

[a] $A \propto Q^{0.5}$

[b] $H \propto Q^{0.4}$

[c] $\text{Travel time} = \frac{\text{dist.}}{\text{velocity}} = \frac{\text{dist.}}{\text{Flow/X-Sect.A}}$

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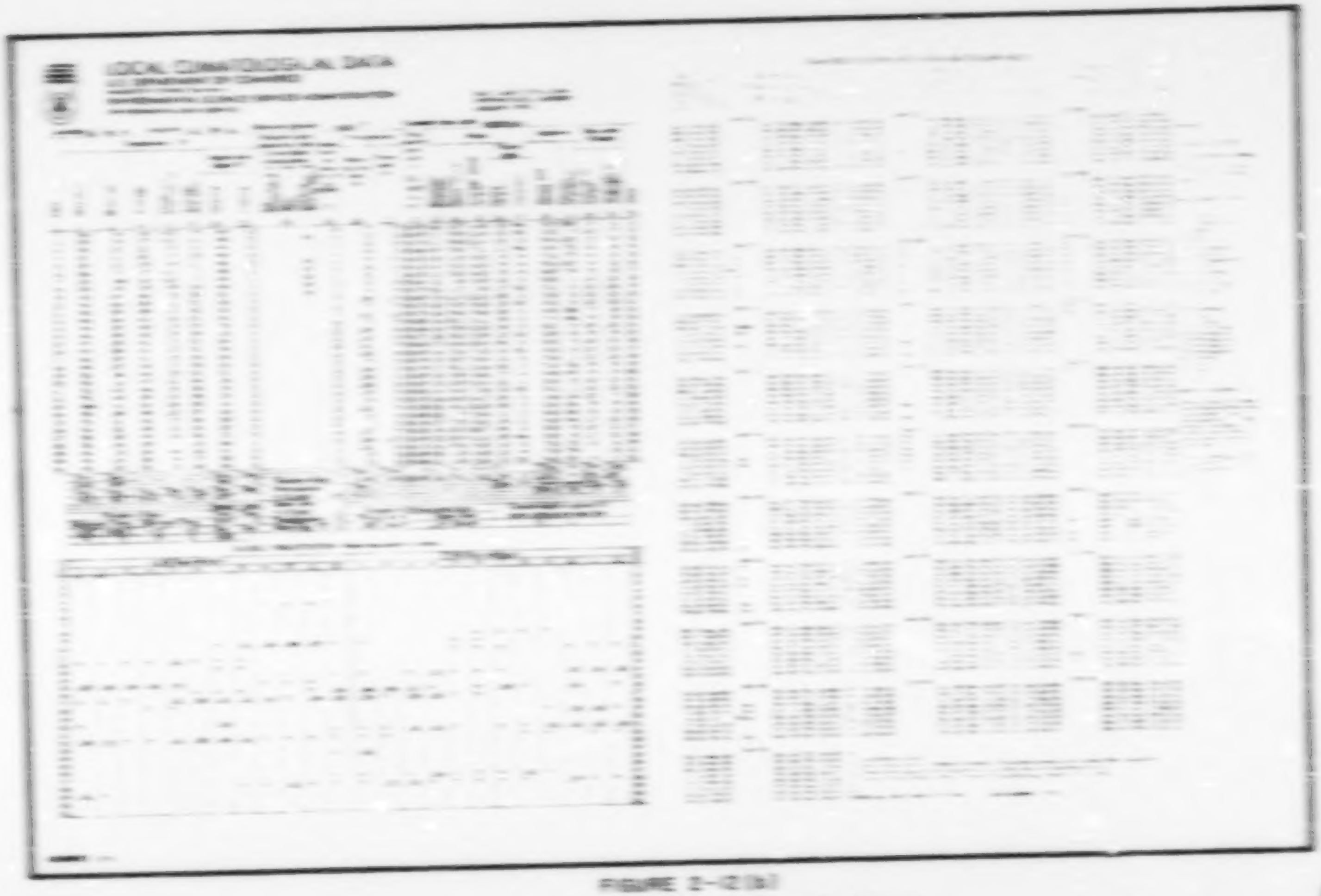


LOCAL CLIMATOLOGICAL DATA
U.S. DEPARTMENT OF COMMERCE

FIGURE 2-12(b)

SAMPLE LOCAL CLIMATOLOGICAL DATA SHEET

In order to establish the relationship between mass discharges and receiving water quality, a water quality model of the receiving water is needed. In addition, the model is used in the development of cost-effective pollution abatement alternatives through an understanding of the cause and effect relationship between the point and non-point source loads and the receiving water quality. Since the reliability of water quality models is directly dependent on the extent and reliability of the water quality data that are used for calibration, a sound water quality data base is essential for a successful 208 study.

A first step in assembling water quality data is to obtain a STORET retrieval of water quality at stations within the general study area limits. "STORET" is the acronym used to identify the computer oriented U.S.E.P.A. management information system for STOrage and RETrieval of water quality, streamflow, municipal waste facility inventory, fish kill, and other related data (Reference: 8). Water quality data may be retrieved from STORET in statistically analyzed form or in raw form and graphical displays.

The amount of data available from STORET may be quite sparse, or very extensive. Data handling and analysis is often more effectively accomplished if an initial step of identifying what is available is first performed. Next, the actual data is secured and compiled in an orderly fashion. Indiscriminate requests for data retrievals can literally inundate you with paper, and complicate the task of organizing and evaluating it. A more effective approach is to make a series of sequential retrievals and thus have much of the sorting and organizing accomplished by the computer system.

Data should provide an initial sense of what is going on -- the general levels of concentration of specific parameters for comparison with standards or objectives. Data should further indicate where things are happening, that is where in the stream changes occur, or whether problems tend to occur in certain locations. Since there are seasonal changes in stream flow, temperature, rainfall, and activity (construction, irrigation, recreation, for example) data should indicate when certain quality levels occur or problems manifest themselves.

To access stations and data, the analyst must know the station numbers or follow a program which searches selected geographical areas. A procedure is available to retrieve data for 208 areas using a keyword. EPA is presently involved in a program which will result in the publication of a simple STORET users manual. Generally, the 208 agencies can contact EPA and or the states to determine the availability of STORET information that can be retrieved. Table 2-4 lists the names, addresses and telephone numbers of the persons to contact for information and assistance concerning the STORET retrieval system.

Since the preliminary impact analysis is made on an average annual basis, an EPA STORET inventory retrieval is a valuable initial data base. An inventory provides the user with a statistical evaluation of all the available data for each station within the geographical search limits. A total inventory of all variables is not necessary, since many of the parameters listed in a total inventory will be of little use in the preliminary impact analysis. However, the water quality parameters are obtained at all stations on the main stem of the river and at all tributary stations.

In addition, raw data retrievals will be necessary to obtain water quality data during times of low river flows or during the rainy seasons if they exist. A raw data retrieval provides the user with the individual data that went into the statistical summary of the inventory. Special programs are available to plot stream data profiles, and to perform seasonal analysis and regressions.

As an aid in retrieving and assembling data, Table 2-5 presents a list of river water quality variables that are generally useful in analyzing dissolved oxygen, eutrophication and coliform problems. For river dissolved oxygen analyses, the minimum data requirements are dissolved oxygen, water temperature, and BOD_5. In saline waters, chloride or salinity measurements are required to determine the reduction in the dissolved oxygen saturation level associated with the salinity. It is recommended that pH data be reviewed to identify river segments with extreme pH values. Long-term BOD tests measure ultimate oxygen demand which is the driving force in the oxidation of BOD. Long-term BOD tests

TABLE 2-4

STORET POINTS OF CONTACT

	Point of Contact	User Assistance
Region I	Louis Gitto, Chief Systems Analysis Branch John F. Kennedy Federal Bldg. Boston, Massachusetts 02203	Louis Gitto
Region II	Herbert Barrack, Director Management Division 26 Federal Plaza New York, New York 10007 (212) 264-2520	Jack Sweeney (212) 264-4750
Region III	Larry Miller, Chief Water Quality Monitoring Office Surveillance & Analysis Division Curtis Building 6th & Walnut Streets Philadelphia, PA 19106 (215) 597-9823	Ted Standish (215) 597-8046
Region IV	John Marlar, Chief Technical Support Branch 1421 Peachtree Street N.E. Atlanta, Georgia 30309 (404) 526-3012	Dan Barber (404) 526-5989
Region V	Christopher Timm, Director Surveillance & Analysis Division 230 S. Dearborn Street Chicago, Illinois 60604 (312) 353-6738	Stu Ross (312) 353-2061
Region VI	David White, Chief Technical & Administration Systems Branch 1600 Patterson Street Suite 1100 Dallas, Texas 75201 (214) 749-1176	David White
Region VII	Walter Robohn, Federal Regional Council Representative 1735 Baltimore Avenue Kansas City, Missouri 64108 (816) 374-5495	Dennis Degner (816) 374-2018 758-2018

TABLE 2-4
(Continued)

STORET POINTS OF CONTACT

	Point of Contact	User Assistance
Region VIII	Keith Schwab, Director Surveillance & Analysis Division 1860 Lincoln Street Suite 900 Denver, Colorado 80203 (303) 837-4935	Tom Entzminger (303) 837-4985 FTS 327-4985
Region IX	Clyde Eller, Director Surveillance & Analysis Division 100 California Street San Francisco, California 94111 (415) 556-7858	William Lewis (415) 556-7550
Region X	Dr. Gary O'Neal, Director Surveillance & Analysis Division 1200 6th Avenue Seattle, Washington 98101	Claudia Rock (206) 399-1580

TABLE 2-5

STORET CODES FOR VARIABLES USED IN PRELIMINARY IMPACT ANALYSIS

STORET Code No.	Variable	Problem: BOD-Dissolved Oxygen	Problem: Eutrophication	Problem: Public Health	Problem: Other
00300	Dissolved Oxygen	X	X		
00301	Percent D.O. Saturation	X	X		X
00010	Temperature	X	X	X	X
00400	pH		X		X
00525	SS				X
00530	TDS			X	
00310	BOD_5	X			
00319	Long-Term BOD	X			
00320	Long-Term BOD with Nitrification Inhibitor	X			
00605	Organic Nitrogen	X			
00610	NH_3-N[(a)]	X	X		
00615	NO_3-N	X	X		X
00620	NO_2-N	X	X		X
00665	Total Phosphorus		X		
00660	Ortho Phosphorus		X		
31507 31509	Total Coliform			X	
31515 31516	Fecal Coliform			X	
00060	Stream Flow(b)				

(a) Un-ionized ammonia can be computed from pH, temperature and NH_3-N

(b) If flow is retrieved, stream loadings can be calculated performed with and without a nitrification inhibitor measure the carbonaceous and total BOD respectively. The nitrogenous BOD is computed as the total BOD minus the carbonaceous BOD. Organic nitrogen, ammonia, nitrite, and nitrate serve as indicators of nitrification in a river because organic and ammonia nitrogen are oxidized to nitrite and nitrate.

Total coliform bacteria measurements are generally sufficient to identify contaminated sections of receiving waters. However, it is recommended that, when available, fecal coliform data also be analyzed to further define the fecal component of the coliform group.

Other potential water quality problems such as suspended solids, total dissolved solids, heavy metals, toxic organic compounds and pesticides should also be investigated by comparing existing water quality data to standards.

State agencies are required by Section 305 of Public Law 92-500 to conduct water quality surveys and to submit to the regional administrator a water quality inventory describing the water quality of all navigable waterways in the state on a yearly basis. Generally, the state monitoring programs vary from the measurement of flow and dissolved oxygen to the collection of the parameters shown in Table 2-6. Theoretically this data, along with U.S.G.S. data and other water quality data, is contained in STORET. However, normal time lags and general inefficiencies may prevent this from happening. Therefore, it is important to contact the individual states to obtain the most recent available water quality data. Table 2-7 lists an agency contact in each of 30 states. Additional sources of water quality data are listed in Table 2-8.

The first priority in reviewing the STORET data retrieval, or data from other sources, is to construct spatial water quality distributions for various time periods. For example, a review of STORET data for ten stations on a river might show seven of the stations were sampled on the same day, or during the same week or month. Extracting these data and plotting spatial distributions for as many constituents as possible is essential since these plots provide a "picture" of river water quality at a certain period in time.

TABLE 2-6

WATER QUALITY PARAMETERS COMMONLY MONITORED BY STATES*

Parameter	Number of States
Flow	47
Dissolved Oxygen	47
Coliform bacteria	45
Nitrogen (any form)	39
Phosphorus (any form)	35
pH	35
BOD/COD/TOC	27
Water temperature	29
Turbidity	26
Solids (any type)	27
Metals (any type)	17
Chlorides	19
Alkalinity	15
Conductivity	16
Color	11
Sulfate	14

*Only parameters specifically mentioned as being part of the State's monitoring program are counted. Only parameters listed by at least 10 States are included.

TABLE 2-7

STATE WATER QUALITY SURVEY

	Point of Contact
Alabama	Ann Cummings Water Improvement Commission State Office Building Montgomery, AL 36104 (205) [illegible]
Arizona	Phyllis [illegible] Water Quality Control Board 1740 West Adams Phoenix, AZ 85007 (602) 271-5455
Arkansas	R. T. Wilson Control and Ecology 8001 National Drive Little Rock AR 72209 (501) 371-1701
California	Phil [illegible] State Water Res. Control Board 1416 9th Street Sacramento, CA 95814 (916) 322-[illegible]
Colorado	John [illegible] P.O. Box 150 [illegible], CO [illegible] (303) [illegible]
Connecticut	Charles [illegible] Department of Environmental Protection Water Compliance Unit State Office Building (Room 117) Hartford, CT 06115 (203) [illegible]
D.C.	James [illegible] Water Quality Control Division 415 [illegible] Street N.W. Washington, D.C. 20001 (202) [illegible]
Florida	H. [illegible] Mitchell Department of Pollution Control 2562 Executive Center Circle East Tallahassee, FL 32301 (904) 488-[illegible]
Georgia	Michael [illegible] Department of Natural Resources 270 Washington Street Room 820 Atlanta, Georgia (404) [illegible]
Idaho	[illegible] Ralston Department of Health and Welfare State House Boise, ID 83720 (208) [illegible]
Illinois	[illegible] Illinois Environmental Protection Agency 2200 Churchill Road Springfield, IL 62706 (217) [illegible]
Indiana	[illegible] Chang Indiana Stream Pollution Control Board 1330 West Michigan Indianapolis, Indiana
Iowa	Jim [illegible] Iowa Department of Environmental Quality 3920 Delaware Avenue P.O. Box 3326 Des Moines, IA 50316 (515) [illegible]
Kansas	[illegible] State Department of Health Water Quality and Point Source Data Division 740 Forbes AFB Topeka, Kansas (913) 296-[illegible]
Kentucky	Douglas [illegible] Griffin Division of Water Resources Department of Natural Resources and Environmental Protection 5th Floor Capital Plaza Tower Room [illegible] Frankfort, KY 40601 (502) 564-[illegible]
Louisiana	David [illegible] Bureau of Environmental Health State Office Building P.O. Box 60630 New Orleans, LA 70160 (504) 527-[illegible]
Maryland	[illegible] Tawes State Office Building Maryland Environmental Service Annapolis, MD 21401
Massachusetts	[illegible] Massachusetts Division of Water Control 100 Cambridge Street (Room 1901) Boston, Mass. (617) 727-[illegible]
Michigan	Bruce [illegible] Michigan Water Resources Commission [illegible] Building - 8th Floor Lansing, MI 48926 (517) 373-[illegible]
Minnesota	Bob [illegible] Pollution Control Agency 1935 W. County Road Roseville, MN (612) [illegible]
Mississippi	[illegible] Mississippi Air and Water Pollution Control P.O. Box 827 Jackson, Mississippi (601) 354-[illegible]
Missouri	[illegible] Department of Natural Resources Clean Water Commission P.O. Box 176 Jefferson City, MO 65101 (314) 751-[illegible]
Nebraska	Judy [illegible] Department of Environmental Control Lincoln, NE 68509 (402) 471-[illegible]

TABLE 2-8
STATE WATER QUALITY AGENCY

	Point of Contact
New Jersey	John Ruggero N. J. Dept. of Environmental Protection P.O. Box 2809 Trenton, NJ (609) 292-[illegible]
New Mexico	Mike [illegible] Water Quality Section [illegible] Building P.O. Box [illegible] (505) 827-[illegible]
New York	Phil Dey Department of Environmental Conservation 50 Wolf Road Albany, NY (518) 457-[illegible]
North Carolina	[illegible] Dept. of Natural Economic Resources P.O. Box [illegible] Raleigh, NC 27611 (919) [illegible]
North Dakota	[illegible] North Dakota State Department of Health State Capitol Bismarck, ND 58505 (701) 224-[illegible]
Ohio	[illegible] Environmental Protection Agency 361 East Broad Street Columbus, Ohio 43216 (614) 466-[illegible]
Oklahoma	[illegible] Water Quality Div. P.O. Box [illegible] Oklahoma City, Okla. (405) 271-[illegible]
Oregon	[illegible] Department of Environmental Quality [illegible] Portland, Oregon (503) 229-[illegible]
Pennsylvania	John [illegible] State of Penn. Management Services Division P.O. Box [illegible] Fulton National Bldg. 3rd and Locust Streets Harrisburg, PA 17120 (717) 787-[illegible]
South Carolina	[illegible] South Carolina Health and Environmental Control (Room [illegible]) [illegible] Bull Street Columbia, SC 29201 (803) 758-[illegible]
Texas	[illegible] Water Quality Board P.O. Box [illegible] Austin, TX (512) 475-[illegible]
Vermont	[illegible] Vermont State Department of Water Resources Water Quality Division State Office Bldg. Montpelier, VT 05602 (802) [illegible]
Virginia	[illegible] Virginia State Water Control Board 2111 N. Hamilton Street P.O. Box [illegible] Richmond, VA 23230 (804) 770-[illegible]
Washington	Robert Jones Dept. of Ecology State of Washington [illegible] P.O. Box [illegible] Olympia, Washington 98504
West Virginia	[illegible] Department of Natural Resources [illegible] Street Charleston, West Virginia (304) 348-[illegible]
Wisconsin	[illegible] Wisconsin Dept. of Natural Resources P.O. Box 450 Madison, Wisconsin 53701 (608) 266-[illegible]

TABLE 2-8

SUMMARY OF SOURCES OF WATER QUALITY DATA[a]

1. Bureau of Reclamation (Dept. of Interior)
2. U.S. Army Corps of Engineers
3. Environmental Protection Agency (Regional Offices)
4. U.S. Forest Service (Dept. of Agriculture)
5. Fish and Wildlife Service (Dept. of Interior)
6. U.S. Geological Survey (Dept. of Interior)
7. National Weather Service (Dept. of Commerce)
8. National Water Quality Surveillance System (EPA)
9. State, County and City Health Departments
10. Local University Biology, or Environmental Engineering Departments
11. Engineering Reports (such as 303-E Basin Plans and 201 Facilities Plans)

[a] See Appendix B for details for water quality data sources

Spatial water quality profiles should be developed for various river flow and seasonal conditions. Summer low flow conditions are generally critical with regard to dissolved oxygen. High river suspended solid levels occur during periods of peak surface runoff. Wet weather spatial surveys reveal stormwater runoff effects.

Water quality data with sufficient spatial detail is not likely to come from a STORET data retrieval. Detailed spatial water quality is generally the result of a special water quality study. In some instances the data collected during these studies are stored in STORET. Consequently, State governmental environmental agencies can be a source of extensive river quality data that is not a part of STORET. For example Figure 2-13, presents three spatial dissolved oxygen distributions in the Black River, New York measured between 1969 and 1973. Plots (a), (b), and (c) in Figure 2-13 represent data obtained from STORET, N.Y. State Department of Environmental Conservation, and an EPA sponsored study of the Black River respectively. A review of the STORET data does not reveal a dissolved oxygen problem. The State data shows two river dissolved oxygen measurements less than the standard. Finally, the data collected during the special study provides a detailed spatial dissolved oxygen distribution of the Black River which clearly shows a 25 mile reach of river where the standards were not met.

Although the primary goal of a preliminary water quality inventory is to produce spatial distributions of various constituents, it is also advisable to isolate some temporal water quality data. Temporal dissolved oxygen data may indicate that algal photosynthesis and respiration significantly affect river dissolved oxygen. Data for six stations on the Truckee River is shown in Figure 2-14. The diurnal dissolved oxygen data for Station 4 shows that the peak afternoon dissolved oxygen concentration of 10 mg/l decreases to a minimum nighttime concentration of 4 mg/l, representing a dissolved oxygen change of 6 mg/l over the day.

Should insufficient river water quality data exist, it is still appropriate to proceed with the preliminary analysis in order to locate regions of

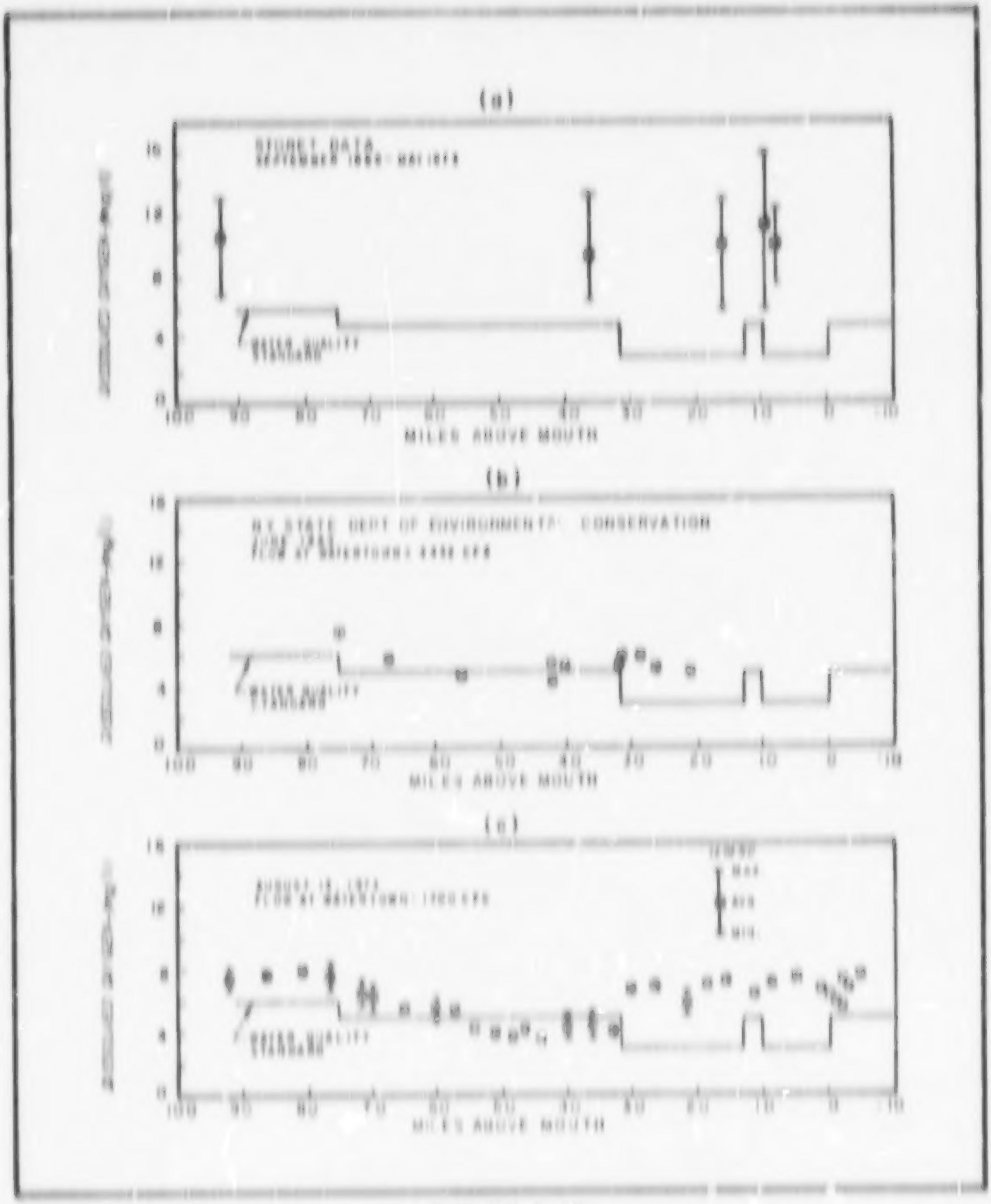


FIGURE 2-15
COMPARISON OF DISSOLVED OXYGEN DATA
(BLACK RIVER, N.Y.)

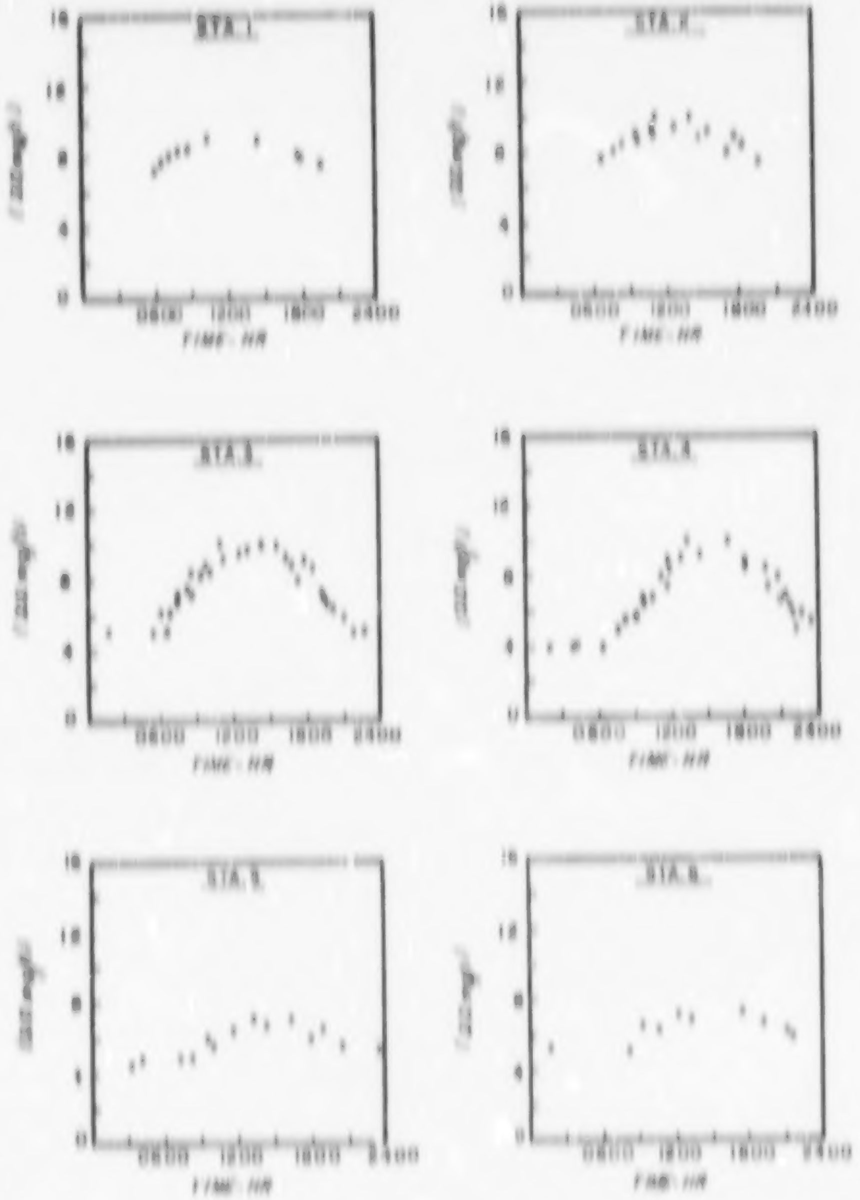


FIGURE 2-14
DIURNAL DISSOLVED OXYGEN VARIATIONS
(TRUCKEE RIVER, NEVADA)

probable water quality problems. The impact analysis can be performed using estimates and empirical relationships as discussed subsequently.

Visual observations of the study area during dry and wet weather is an additional source of data. Field trips can provide the analyst with increased understanding of the 208 study area and its complex problems. Inspections provide information on the exact location of point wastewater discharges, the location of NPS runoff inflow, areal extent of instream weed growths, and the extent of the lateral mixing zones below wastewater discharges or tributary inflows. In addition, field trips usually bring the analyst in contact with local residents who prove to be invaluable sources of qualitative data with respect to water use and misuse.

A field trip made during a storm event can provide data on the location of stormwater overflow points. Wet weather observations also lead to qualitative identification of instream water quality problems such as excess suspended solids or floatables. Finally, visual inspections of the 208 study area can pinpoint the location of NPS sediment sources. Such sources, as abandoned open cuts or construction activity, can be discovered on field trips.

2.5 Waste Source Identification and Evaluation

The procedures to be used for the preliminary problem assessment are based on a mass balance analysis of the receiving water. The need for reasonable estimates of the mass emission rates or loads is, therefore, apparent. The characterization of the various types of discharges is based on their origin and their variability. The minimal characterization is an estimate of the long term average mass discharge rate, typically in units of pounds/day. For certain classes of discharges, it may be necessary to have an estimate of the seasonal variation of the mass discharge rate over the year, if this variation is significant. For preliminary analysis, a significant variation is a monthly average variation factor of three times greater than the long term mean. This judgement is based on the probable accuracy of the estimating procedures used for other sources of mass for which measurements are usually not available. A three-fold variation appears to be the range of the uncertainty in these estimates and this uncertainty sets the relative accuracy of the entire analysis.

To understand this choice of criteria, it is necessary to realize that for a given planning area the estimates recommended for use in the preliminary assessment, in lieu of actual site-specific data, are the averages of the long term average concentrations from the runoff of many cities, agricultural lands, etc.. It is also necessary to consider these data as a statistical sampling problem from a set of random variables. As an example, for the urban combined sewer overflow concentration of suspended solids from many cities, an estimate is needed of how far in error the use of the mean suspended solids concentration from this set of random variables is from the actual concentrations. A guide is that for sets of random variables with a coefficient of variation of approximately one, a greater than three-fold variation has a probability of less than 10%. The 10% probability appears to be a reasonable bound and is the basis for the selection of a three-fold variation.

This probable variability sets the level of uncertainty in the overall preliminary assessment. If the seasonal variation of a source is less than this three-fold variation, its inclusion is not warranted since it is a refinement above the probable level of accuracy of the overall preliminary assessment.

2.5.1 Continuous Point Source Evaluation

Point sources effluent water quality data are available for both municipal and industrial sources of wastewater. Other point sources of pollution include continuous discharges from: faulty sewerage systems; inadequate or filled interceptors; faulty regulators; exfiltration; or continuous overflows at treatment works. It is likely that loading data will not be available for these other point sources. However, municipal wastewater effluent quality data can be obtained from EPA, state, and local regulatory agencies. One of the best sources of these data are 303(e) basin and 201 facility plans. Industrial point source effluent water quality data can be obtained from EPA, state, and local regulatory agencies and from the industries themselves. An additional source of effluent discharge data for the industry of interest is the NPDES and State permits. These are available either from the EPA region, or responsible state agency, or the industries themselves. The Surveillance and Analysis (S&A) division of the EPA region have measured effluent data for many industries. Effluent water quality data exists as flow and associated concentration.

From the flow and concentration data, average annual mass discharge rates for the continuous point sources are calculated for the variables in Table 2-9.

TABLE 2-9

VARIABLES USED IN PRELIMINARY PROBLEM ASSESSMENT

Problem Category	Variables
Dissolved Oxygen	BOD_5 and Total Kjeldahl Nitrogen
Public Health	Total Coliform Bacteria
Eutrophication	Total Nitrogen Total Phosphorus
Other Water Use Interferences	Total Suspended Solids

For total coliforms, the average of the logarithms of the counts is used to calculate the average. Since coliform data are generally log-normally distributed, the arithmetic average is not a suitable measure of the central tendency of the data. Arithmetic averages overweight the few very large measurements.

If adequate data is not available, municipal point source mass discharges can be calculated based on population (see Simplified Mathematical Modeling of Water Quality(1)) and industrial mass discharges can be estimated from the literature based on production rates (9).

The annual average point source loads are tabulated and located with respect to a river mileage coordinate system. Some of the sources can be eliminated from further analysis if the loads they discharge to the river are considered insignificant when compared to the other point source loads at or near that location. This may not be the case for the analysis of projected conditions where certain sources are controllable and others are less so.

The mass discharge rates for the point sources in the hypothetical South River 208 study area are presented in Table 2-10. Loading rates are presented for total nitrogen, total phosphorus, total suspended solids, BOD_5 and total coliform bacteria. Data are given for the upstream river quality, the Beaver River quality, Brown Pulp and Paper (industry), Jefferson Municipal Sewage Treatment Plant and the American Paper Company (industry).

In Table 2-10, the nitrogen, phosphorus and coliform loading rates from the two industries are considered insignificant and are not included in the preliminary impact analysis. This is a judgement based on the extremely small magnitude of the industrial loading rate when compared the other point sources.

2.5.2 Tributary Sources

Tributaries to the main receiving water and the quality of the farthest upstream point of the region being considered are also evaluated. These sources are treated as continuous point sources to the main reach of the receiving water. The evaluation of the magnitude of their contribution is also required for the analysis. In some cases, water quality data exists and the average concentrations can be obtained from measurements. This is assumed to be the case for the illustrative problem. If this is not the case, preliminary analyses of the tributary and upstream drainage basins are required. The methods to be used are identical to those to be presnnted for the main reach. The analysis is done for the portions of the drainage area for which there are insufficient measurements.

Seasonal variations are considered if the measured concentrations show a regular annual trend and the magnitude of the seasonal variation from the annual mean is three-fold or greater.

The variation of concentration with river flow is also of interest. Substances associated with point sources show a dilution effect whereas

TABLE 2-10

SUMMARY OF POINT LOADS FOR HYPOTHETICAL SOUTH RIVER EXAMPLE

Source	Flow (cfs)	Total Nitrogen		Total Phosphorus	
		mg/l	lbs/day	mg/l	lbs/day
Upstream Q.	500[a]	0.2	540[b]	0.05	135[b]
Beaver R.	250[a]	0.5	675[b]	0.10	135[b]
Brown P & P	1.6	0	0	0	0
Jeff. STP	19.8	20	2138	10	1069
Amer. Pap.	0.8	0	0	0	0

Source	Flow (cfs)	Total SS		BOD_5		Total Coliform	
		mg/l	lbs/day	mg/l	lbs/day	No. 100/ml	No./Day
Upstream Q.	500[a]	10	27,000[b]	1.0	2,700[b]	500	6.1×10^{12}[b]
Beaver R.	250[a]	20	27,000[b]	1.5	2,025[b]	1,000	6.1×10^{12}[b]
Brown P & P	1.6	50	432	50	432	0	0
Jeff. STP	19.8	30	3,208	30	3,208	10,000	4.8×10^{12}
Amer. Pap.	0.8	200	864	500	2,160	0	0

[a] Average annual flow

[b] Loads at other flow regimes are computed proportional to flow

sources associated with surface runoff and groundwater flow interact in more complex ways. This issue is beyond the scope of a preliminary analysis but is addressed in subsequent chapters.

2.5.3 Intermittent Urban Point Sources

The principal concern is the overflows and bypasses of the sewerage system during rainfall events. The precise and detailed evaluation of the mass discharges from a complex metropolitan region is a task which can occupy the entire efforts of a planning study. It is of interest, therefore, to estimate the importance of these mass discharges in comparison to all other mass sources. A method is required that can give approximate results which are suitable for comparative purposes.

Methods for estimating sewer overflow quantity and quality have been developed in recent years. The result is a series of estimating techniques and computer-based models which span a level of complexity from minute-to-minute simulations that consider the detailed hydraulics and mass transport in the urban watershed and sewerage system, to less complex models that process hourly rainfall data and associated pollutant concentrations in the resulting runoff. Appendix A identifies and describes a number of such models. From the point of view of a preliminary analysis, it appears that many of these methods are too detailed and cumbersome if what is required is an estimate of the significance of urban sewer overflow relative to the other sources of mass being considered. Examples of these methodologies are given in References 10 and 11. In this Manual, a simple and direct method is suggested which is based on estimating the average mass discharge rate as the product of the average concentration in the runoff, and the average quantity of runoff. That is, if $\overline{W}_O$ is the long term average mass discharge rate from an overflow point, then

$$\overline{W}_O = c\ \overline{C}_V\ \overline{I}_T\ A \tag{2-5}$$

where:

$\bar{c}$ is the average concentration (mg/l)

$\bar{C}_v$ is the average runoff coefficient (unitless)

$\bar{I}_T$ is the average rainfall divided by the period of averaging, T (in/hr).

A is the drainage area (acres).

This equation assumes that the random variables $\bar{c}$, $\bar{C}_v$, and $\bar{I}_T$, are uncorrelated. Recent analyses of available data (10) indicate that this assumption is reasonable, especially if a large drainage area is served by a single rain gage.

Treating the runoff coefficient as a random variable appears, at first glance, to be unnecessary since, in principle, it is deterministically related to the processes of rainfall and flow over catchments of definable properties. However, the rainfall itself has properties which are not definable from normally available rainfall records. The critical element is the spatial extent of the rainfall represented by the measurement at a point rain gage. It is this component of the actual runoff which is behaving randomly. Therefore, it appears reasonable to treat the overall runoff coefficient, as a random variable. An analysis of runoff coefficients given in Figure 2-15 indicates that a relationship exists using population density as a measure of the degree of imperviousness. For low and medium population densities, a mean of 0.3 ± 0.15 seems reasonable, and results in approximately a two-fold uncertainty.

Similiar arguments can be made for treating the runoff concentration as a random variable. Although, in principle, the mass in the runoff is related to the accumulations of mass in the catchment and sewerage system, it is a difficult task to formulate the relationships in a way that is broadly applicable. All models that attempt this calculation require extensive calibration data on a number of events in order to give reasonable results. In lieu of such an effort, it appears justified

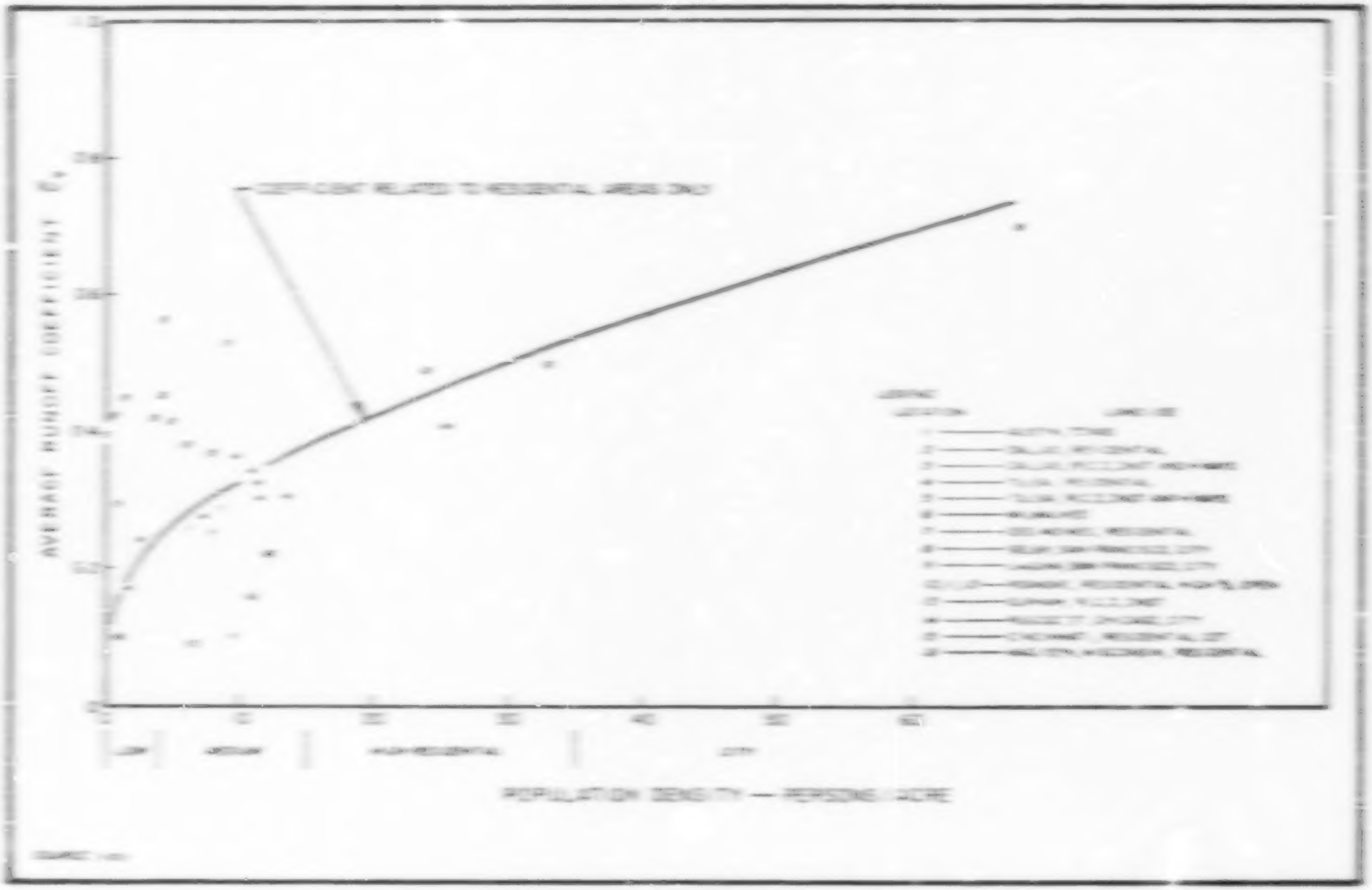


FIGURE 2-15
RUNOFF COEFFICIENT RELATED TO POPULATION DENSITY

to regard the concentration as varying randomly and require only that its statistical properties be estimated.

For the preliminary analysis the average concentration of the constituents of interest are required. Table 2-11 summarizes the average and standard deviation of the long term average concentrations for the parameters of interest for selected U.S. cities. For BOD and suspended solids, the upper 90th percentile is approximately three times the mean so that for a given city these concentrations can be regarded as being known to within a three-fold uncertainty.

The method is applied in the following way: available data for both quality and quantity of urban stormwater are used if available. Site specific data are aggregated into annual average mass discharge rates (lbs/day) for the preliminary analysis. If available, mass discharge rates are tabulated for total nitrogen, total phosphorus, BOD (5 day), total coliform bacteria and total suspended solids. In addition, the major sewer overflow discharges are located with respect to the river mileage coordinate system. Minor overflow discharge rates should be combined if they are closely spaced. For example, five 0.05 MGD combined sewer overflows within 1 mile of each other may be added together to form a 0.25 MGD overflow at one location.

If site specific separate and combined sewer quality and quantity data are not available, then steps 1 through 9 give a method to estimate the mass discharge rates for the preliminary analysis.

1. Locate major overflows and determine if they are combined or separate sewers
2. Locate and group minor overflows
3. Associate a drainage area (A) (acres) with each overflow
4. From the demographic inventory, estimate a population density (persons/acre) for each urban drainage area. Estimate a mean runoff coefficient C_v for each urban drainage area. Figure 2-15 or alternate techniques may be used.
5. Obtain the average annual rainfall from the weather bureau

TABLE 2-11

SUMMARY OF STORMWATER POLLUTANT CONCENTRATIONS FOR SELECTED U.S. CITIES[a]

Pollutant	Stormwater Overflow Concentrations[b]					
	Separate Sewers[c]			Combined Sewers[d]		
	Mean	Standard Deviation	v[e]	Mean	Standard Deviation	v[e]
BOD_5	27	25	0.9	108	36	0.3
Suspended Solids	608	616	1.0	372	275	0.7
Total Coliforms	3×10^5	-		6×10^6	-	
Total Nitrogen (as N)	2.3	1.4	0.6	9	6	0.7
Total Phosphorus (as P)	0.5	0.4	0.8	2.8	2.8	1.0

[a] Reference (12)

[b] All units mg/l, except coliforms, MPN/100 ml

[c] Summary of the averages of twenty cities

[d] Summary of the averages of twenty-five cities

[e] v = coefficient of variation = Standard Deviation ÷ Mean

v describes the relative variability of the average concentration of pollutants in runoff; as v increases, this indicates that the pollutant concentration is becoming more variable. E.g., v > 1 highly variable, v = 0.2 not very variable.

6. Convert average annual rainfall, V, to average hourly intensity, $\bar{I}_T$. $\bar{I}_T$ (inches/hour) = V (inches annual rainfall) ÷ T (hours in averaging period), i.e., $\bar{I}_T = V/T$.
7. Calculate average annual runoff, $\bar{Q}_U$ (cfs) = $\bar{I}_T$ (in/hr) $\bar{C}_V A$ (acres).
8. Using the average concentrations given in Table 2-11 for combined and separate sewer overflow, estimate the average annual mass discharge rate, $\bar{W}_U$, for each discharge. $\bar{W}_U$ (lbs/day) = 5.4 $\bar{C}$ (mg/l) $\bar{Q}_U$ (cfs).

The average annual effect of the urban stormwater runoff on the water quality of the hypothetical South River is estimated using this procedure. The annual rainfall in the South River Basin is 40 inches/year so that $\bar{I}_T$ = 0.00457 inches/hr. Approximately ten square miles (6400 acres) of the total 20 square mile area of Jefferson City is sewered with combined sewers. The remaining area is unsewered. The example further makes the simplifying assumption that in Jefferson City there is no provision at the municipal sewage treatment plant for the acceptance of any stormwater. Therefore, the total untreated load flows directly to the South River.

The population density of the combined sewer area is 20 persons per acre. From Figure 2-15 the runoff coefficient at 20 persons per acre is $\bar{C}_V$ = 0.42. The average intensity and average runoff coefficient gives an average stormwater overflow from Jefferson City of $\bar{Q}_U$ = 12.3 cfs.

Since the combined sewers in Jefferson City are evenly spaced over the entire 5 miles of city, the loads are expressed as lbs. per day of a constituent per river mile. The sewer overflows are combined with the pollutant concentrations in Table 2-11 to yield non-point source mass discharge rates. These rates are included in the summary table of non-point sources in Section 2.5.2.2.

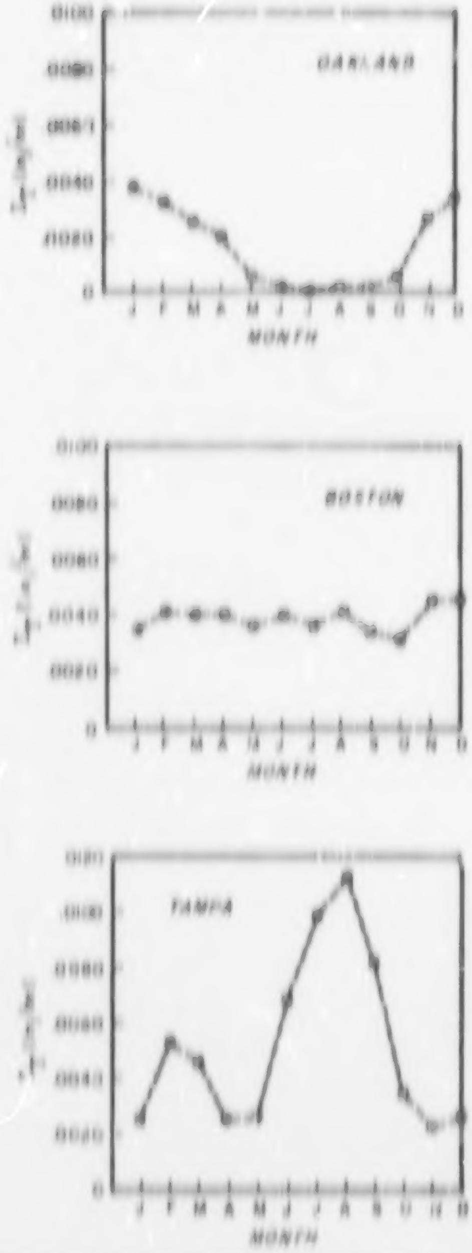
The major difficulty with a long term average analysis of transient stormwater discharges is that the discharge occurs only during a rainfall and this can cause water quality problems during the transient discharge. Even if the average mass discharge rate is small, it is necessary to perform an approximate analysis of the probable effect during such an event. Consider the impact of a continuous rainfall and runoff lasting 3 to 5 days. During this type of storm the rainfall intensity can be 5 to 10 times greater than the average annual intensity. In addition, the base river flow can increase 2 to 5 times the average flow preceding the storm. This combination of rainfall and runoff can be caused by the slowly moving frontal storms which take 3 to 5 days to pass over the drainage basin. Although it is difficult to assess in a preliminary way the probability of occurrence of such an event, this type of storm provides a rough basis for analysis of a critical but not very improbable event. An alternate possibility is a localized storm which does not appreciably change stream flow.

For the South River Basin, rainfall records indicated that a 3-day storm intensity of 7 times the annual average rainfall intensity is not uncommon in the summer. In addition, the base river flow increases to 3.2 times the annual average flow during these storms, as shown by an inspection of the stream hydrograph. Therefore, for the preliminary impact analysis, the storm load is assumed to be 7 times the annual average mass discharge rate.

The seasonal variation of the average urban stormwater mass discharge is due primarily to the seasonal variation in rainfall volume and storm frequency. Seasonal rainfall variations can be quite substantial, in some cases exceeding a three-fold change. Some typical seasonal rainfall variations in intensity are illustrated in Figure 2-16.

2.5.4 Non-Point Sources (NPS)

Non-point source pollution is defined as pollution which enters a water body from diffuse origins on the watershed and does not result from discernible, confined or discrete conveyances. The contribution of non-point sources can be a substantial and significant portion of the total sources that impact the receiving waters being considered. As a consequence, an estimate of their magnitude and receiving water impact is required for rational preliminary analysis. The available methodology for making quantitative estimates of the magnitude of non-point source loading rates is analogous to that available for stormwater related urban point



SOURCE (18)

FIGURE 2-16
AVERAGE MONTHLY RAINFALL INTENSITY

sources. Complex computer models which attempt a deterministic and detailed calculation on short time scales are being developed but, as in the case of the urban stormwater models, their application, if warranted, requires extensive field data and detailed verification analysis. The models cannot be applied without such an effort since they are not predictive without suitable calibrations.

A class of methods being developed are based on soil erosion and sediment transport as the principal source of the non-point source mass reaching the receiving water. The erosion rate is computed using the Universal Soil Loss equation which relates the sediment yield of an area to a rainfall factor (rainfall erosion potential), soil erodibility factor (topographic slope and steepness factor), cropping management factor (related to extent of vegetation cover), and erosion control practice factor. The ratio of sediment generated in the region of analysis to that reaching the receiving water is used to account for the sediment transport. In order to compute the mass discharge rate of nutrients and BOD, it is further assumed that these constituents are a fixed multiple of the sediment mass reaching the receiving water. Since several of these factors can be uncertain up to an order of magnitude, the estimate of sediment loading to the receiving water can have a substantial uncertainty associated with it. A more detailed exposition and evaluation of this method is contained in Chapter 4.

Therefore, the method that is recommended for the preliminary analysis is, as in the case of the stormwater evaluation, a simple estimate based on the average annual yields of drainage basins of various categories. For the purposes of the preliminary analysis, sources of non-point loads are separated into the following land use types: agriculture, feedlots, forest, and non-sewered urban. The choice of the long term scale (annual) and large spatial scale (drainage basin wide) is consistent with the temporal and spatial scale of the preliminary impact analysis. Although seasonal effects are addressed in an approximate way, the uncertainty of the annual estimates may exceed the variations due to seasonal effects.

The available literature on non-point source nutrient yield, which are presented in units of pounds/square mile/day, are based on yearly averages reported in the literature. A wide variability in the data is encountered within specific land use patterns. Significantly different nutrient loads are also observed according to the monitoring procedures used to obtain the data. Therefore, the data are chosen in terms of the spatial and temporal scales appropriate for the application. Non-point source load estimates are segregated according to the three basic monitoring procedures generally used to obtain the data. These three procedures are:

1. Seepage Study - These include lysimeter studies and sampling of tile drainage effluent. The water being analyzed has percolated through the soil profile and, thus, may contain significant quantities of leached nutrients.

2. Runoff Study - These studies typically involve very small tracts of land devoted to a single and specific land use. Samples are collected only during runoff events. Water sampled in these studies includes significant quantities of particulate matter with which most of the nutrients are associated.

3. Drainage Area Study - These studies involve continuously flowing streams which drain a particular land type. Flow is usually monitored continuously and samples are periodically collected for nutrient analysis.

Only the results of drainage area study are used for the preliminary analysis since the spatial scale is most appropriate. In addition, it is quite difficult to translate small temporal and spatial scale mass loadings to the quantity which eventually enters the receiving water. For example, if agricultural lands are considered, a large range in yield is possible for both total and inorganic nitrogen and phosphorus depending on the spatial scale to which the data apply. Table 2-12 presents a summary of available data for the three spatial scales. Seepage and runoff studies exhibit a range of at least two orders of magnitude for all nutrient forms reported. The range in the results of

TABLE 2-12

AGRICULTURAL NUTRIENT YIELDS, POUNDS/SQUARE MILE/DAY

1. Seepage Studies - Tile Drainage or Lysimeter Studies

	Nitrogen Yield			Phosphorus Yield		
	Number[a]	Mean	Range	Number[a]	Mean	Range
Total	15	44.0	0.5-172.	9	1.82	0.08-12.1
Inorganic	28	30.4	0.5-128.	6	0.83	0.02- 3.9

2. Runoff Studies- Surface Runoff From Small Test Plots

	Nitrogen Yield			Phosphorus Yield		
	Number[a]	Mean	Range	Number[a]	Mean	Range
Total	25	48.2	1.41-414.	16	9.23	0.17-47.0
Inorganic	14	1.23	0.02-7.2	-	-	-

3. Drainage Area Studies - Stream Sampling

	Nitrogen Yield			Phosphorus Yield		
	Number[a]	Mean	Range	Number[a]	Mean	Range
Total	23	15.	1.9 -58.0	35	0.73	0.05-3.9
Inorganic	17	12.	1.72-32.8	9	0.23	0.05-0.91

4. Comparison of Mean Yields

	Nitrogen		Phosphorus	
	Total	Inorganic	Total	Inorganic
Seepage Studies	44	30.4	1.82	0.83
Runoff Studies	48	1.2	9.23	-
Drainage Area	15	12.	0.73	0.23

[a] Indicates number of studies.

Source: Reference (13)

drainage area studies is somewhat smaller, especially for total nitrogen where the minimum and maximum value differ by about an order of magnitude.

As shown at the bottom of Table 2-12, the different monitoring procedures yield significantly different results. The seepage studies indicate very high nitrogen yields with a high percentage of inorganic or soluble nitrogen being leached from the soil. Similarly, runoff studies indicate similarly high yields for total nitrogen; however, most of this is in the particulate form. Phosphorus yields are higher in the runoff studies than in seepage studies, reflecting the ability of many soils to retain this element. Nutrient yields reported from drainage area studies are significantly lower than seepage or runoff studies. Furthermore, the nitrogen measured in drainage area studies is predominantly in the inorganic form. Apparently, much of the particulate matter observed in runoff events from small plots of land is not transported to perennial stream channels.

Thus, drainage area studies appear to have the widest and most direct application for estimation of nutrient loads to receiving waters. Runoff studies would have application in evaluation of the impact of specific land management practices, e.g., plowing techniques, crop rotations, and fertilizer applications. However, these runoff studies would have to be conducted in conjunction with drainage area studies, in order to quantitatively establish the link between the two. The physical transport and the chemical mechanisms involved in this link may be quite complex, and a substantial technical and financial commitment would be required to establish, calibrate, and verify a quantitative framework for the analysis.

A summary of the drainage basin yields for the various categories of land use are shown in Table 2-13. This table is used for the preliminary assessment of non-point source loading.

Seasonal variations of non-point source loads can be substantial, particularly if the sources are from agricultural lands. It is likely that the variability of the seasonal distribution is a cause of the

TABLE 2-13

RUNOFF AREAL LOADING RATE - POUNDS/SQUARE MILE/DAY[a]
(Average Range)

Land Use	Total Nitrogen	Total Phosphorus	BOD_5	TSS	Total Coliform
Agriculture	15 (1.9-58)	1.0 (0.05-3.9)	40 (6.3-57)	2,500 (449-6,594)	-
Forest	4 (1.3-16)	0.25 (0.01-1.4)	8 (6.3-11)	400 (71-620)	-
Pasture	8 (3.9-13.3)	0.5 (0.4-1.0)	17 (9.4-27)	670 (10-1,320)	-
Feedlots	1,700 (1,080-2,290)	370 (200-610)	-	-	-
Landfill	1,250[b] (50-2,500)	-	15,000 (80-33,100)	-	-
Urban	8 (3.3-28)	1.3 (0.4-7.9)	70 (20-129)	3,400 (305-7,526)	1,000[c] (1,000-24,000)

[a] References 14-38

[b] Runoff concentration in mg/l

[c] Runoff concentration in numbers/100 ml

variability of the estimates in Table 2-13. A method for estimating this variability is discussed in Chapter 4.

2.5.4.1 Urban Non-Point Runoff - Application

The sources of urban runoff considered in this analysis are areas of the city which are not sewered by either combined or separate storm sewers and the runoff from sanitary landfill areas. The non-sewered urban area should be located with respect to the river and its drainage area (square miles) determined. If mass loading rates are available from previous studies, they are used in the impact analysis. Generally, site specific loading rates will not be available and the literature values presented in Table 2-13 should be used to estimate the mass loading rates for total nitrogen, total phosphorus, BOD_5, total coliform bacteria, and total suspended solids.

The sewered urban area of the hypothetical example city, Jefferson City, is 10 square miles. The non-sewered runoff loads, as calculated from the information in Table 2-13, are presented along with the other non-point source loads in Table 2-15. As with the combined sewer overflows, the non-sewered urban runoff occurs only between Milepoints 15 and 20 and is treated as a linearly distributed mass discharge.

2.5.4.2 Rural NPS Runoff - Application

For the preliminary analysis, rural NPS runoff is assumed to originate from forests, agricultural areas, feedlots, pastures, and undisturbed natural areas. If site specific mass discharge rates for total nitrogen, total phosphorus, BOD_5, total coliforms, and total suspended solids are available, they are used in the impact analysis.

If mass discharge data is not available, estimates are made based on land use and total land area. To do this, it is necessary to sub-divide the drainage basin into major land use types. The major land uses are aggregated along the length of the river. For example, agricultural areas may represent ten square miles per linear mile of river in a certain river basin. The mass discharge rate for land uses other than the undisturbed lands is estimated using the drainage areas and the areal loading rates shown in Table 2-13.

Background water quality concentrations are usually available for most drainage basins. In general, background water quality is affected by land uses and water use practices in drainage basins upstream of 208 drainage areas. Therefore, water quality variables will be at concentrations in excess of undisturbed background water quality. If no data is available, background water originating from relatively undisturbed drainage areas can be estimated using the values in Table 2-14.

The cumulative drainage area distribution associated with each land use in the hypothetical South River drainage basin is presented in Table 2-3 and Figure 2-6. In summary, the drainage areas are: upstream, 500 square miles; tributary, 250 square miles; agriculture, 280 square miles; forest, 150 square miles; urban, 40 square miles. In each river reach, the change in drainage area for the agricultural areas and forest are determined and associated with an areal loading rate from Table 2-13. These loading rates are presented in Table 2-15 as linear mass discharge rates (lbs/mi/day). The upstream and tributary mass discharge rates are assumed to be based on observed data and are not calculated from the data in the loading Tables.

2.5.5 Summary Analysis of Mass Discharges

The results of the preliminary loading estimates for each reach of the hypothetical South River are shown in Figure 2-17(a). The distributed sources (lbs/mi/day) are aggregated into the total mass discharge entering the reach of river being considered in order that a comparison to the point loading can be made. Such a comparison can be quite useful in assessing the relative importance of each type of loading. However, until some form of receiving water analysis is performed it is unclear if these loads are producing significant water quality problems.

For the hypothetical South River, the agricultural loads for nitrogen predominate in the upstream reaches; point and combined sewer overflow loads predominate in the downstream reach. The point source for phosphorus

TABLE 2-14

SUMMARY OF BACKGROUND CONCENTRATIONS[a] FROM VIRGIN LAND

Parameter	Concentration Range (mg/l)	Comments
Nitrogen (inorganic)	0.05-0.50	highest concentrations: Iowa, Illinois, Indiana
		lowest concentrations: South, East West coasts
Phosphorus (total)	0.0 -0.20	highest concentrations: Iowa, Nebraska, Dakotas
		lowest concentrations: South, East, West coasts
BOD_5	0.50-3.0	highest concentiations: Iowa, Illinois
		lowest concentrations: South, East West coasts
Coliform (total)[b]	100-2,000	highest concentrations: west of Mississippi River
		lowest concentrations: Northeast, Southwest
Sediment (TSS)	2-100	highest concentrations: Montana, South Dakota, Nebraska
		lowest concentrations: East, West coasts

[a] See Midwest Research Institute (39) for iso-concentration maps of virgin land runoff concentrations

[b] Number/100 ml

TABLE 2-15

SUMMARY OF NON-POINT SOURCE AND COMBINED SEWER LOADS
FOR HYPOTHETICAL SOUTH RIVER BASIN

River Segment (Mile-Points)	Pollutant Source	Total Nitrogen-N lbs/mi/day	Total Phosphorus lbs/mi/day	TSS lbs/mi/day	BOD_5 lbs/mi/day	Total Coliform No./day/mi x 10^{10}
0 - 5	Agriculture	90	6	15,000	240	37
	Forest	37	2	3,200	64	10
	Urban Runoff	-	-	-	-	-
	Comb. Sewer	-	-	-	-	-
5 - 15	Agriculture	195	13	32,500	520	79
	Forest	10	0.6	1,000	20	3
	Urban Runoff	-	-	-	-	-
	Comb. Sewer	-	-	-	-	-
15 - 20	Agriculture	150	10	25,000	400	61
	Forest	8	0.5	800	16	2
	Urban Runoff	26	2.6	6,800	140	49
	Comb. Sewer	120	16	3,940	1,435	36,000
20 - 33	Agriculture	81	5.4	13,460	215	33
	Forest	25	1.4	2,300	46	7
	Urban Runoff	-	-	-	-	-
	Comb. Sewer	-	-	-	-	-

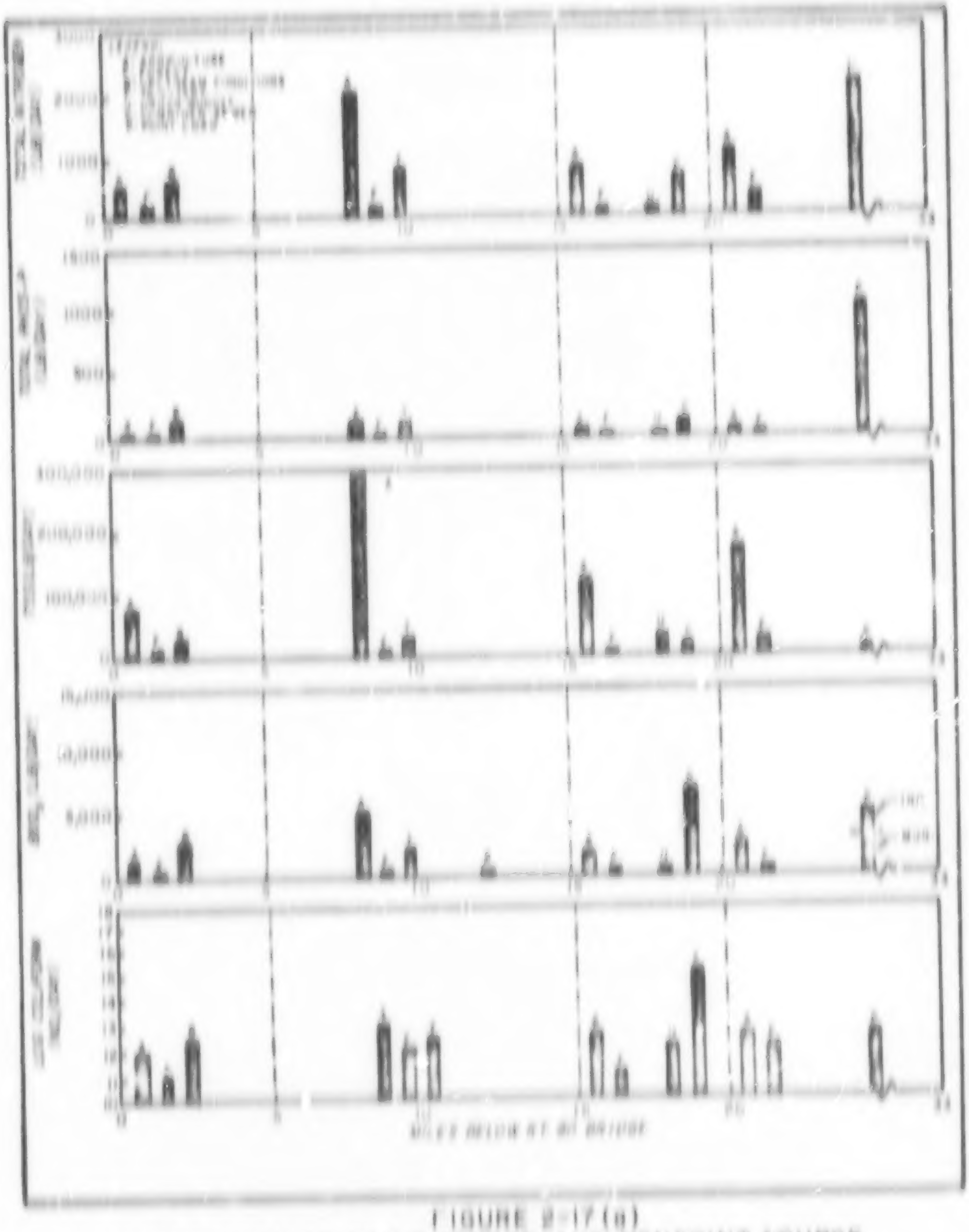


FIGURE 2-17(a)
COMPARISON OF POINT SOURCE AND NONPOINT SOURCE
LOADS PER RIVER SEGMENT
(ANNUAL AVERAGE)
HYPOTHETICAL SOUTH RIVER EXAMPLE

predominates over all other sources, whereas the agricultural source for suspended solids predominates. Substantial quantities of BOD are derived from agricultural, point, and combined sewer overflow, whereas combined overflow dominates the coliform discharge by more than two orders of magnitude.

It is important to realize that the estimates used in this presentation can have a probable three-fold uncertainty due to the uncertainty in the quantities used in the estimates. However, most conclusions reached from an inspection of this figure are not substantially changed. Agricultural, point and combined sewer sources contribute the majority of the load for some or all constituents, whereas forest, upstream inflows, and tributary sources are small in comparison.

In summary, Figure 2-17(a) allows the analyst to put in perspective the relative importance of the point and non-point source pollutional loadings. At this point, the analyst might make a preliminary estimate as to which of the sources of pollution can be omitted from further analysis. What the analysis does not illustrate is the affect that each of the loads has on the instream water quality. Therefore, it is necessary to continue the preliminary analysis in order to determine the impact of these loads on receiving water quality.

2.6 Receiving Water Analysis

The analysis of the water quality of receiving waters is an integral part of a preliminary assessment for a planning study. By establishing the cause and effect relationship between the mass discharges and the resulting concentrations, a rational assessment can be made of the importance of the various sources being considered in terms of their affect on receiving water.

From the point of view of water quality control and management, it is desirable to examine water quality problems in terms of specific constituents, or groups of constituents, which are discharged as a result of man's activities and natural phenomena. One of the initial steps in the planning effort is the identification of the water quality problems presently observed and those projected under future conditions of population growth and development. Having identified the significant present and future water quality problems, it is then necessary to select the constituents which are discharged to the environment, from natural and man-made activities, that are responsible for water quality problems. It is then appropriate to consider a meaningful engineering framework, usually a mathematical model, for analysis of the cause and effect relationships and the methods available for improving and managing the system. The factors which are included in the mathematical analysis are the hydrology and the climatology of the area. From this data, the water balances, the hydraulic circulation, the temperature structures, the assimilation mechanisms and reactions that are involved in the specific water quality problem are developed. Within this framework, each specific water quality problem may be viewed from a characteristic time and space scale which sets the degree of simplicity or complexity of the required mathematical model.

What follows is a discussion of the general principles of water quality analysis in receiving waters. Although the preliminary assessment methodology is restricted to the impact on streams and rivers, the general principles and discussions will form the basis for the subsequent discussions in Chapter 5 that apply to more complex situations and put into perspective the data previously assembled.

2.6.1.1 Time and Space Scales

Certain problems can be attacked relatively quickly, employing the simpler conceptual hydraulic and quality models associated with analysis of long-term phenomena, that is, phenomena associated with a large time scale. The type of problem which is properly addressed in this context is related to the long-term patterns of substances which are conservative, such as dissolved solids or those substances which change at such slow rates that they may be regarded as conservative.

A second scale of time which is appropriate in the investigation of water quality problems is the annual cycle in which the time unit is a week, month, or season. At this intermediate time scale, it may be necessary to account for lateral and vertical spatial variation in water quality. The eutrophication problem is amenable to analysis utilizing this intermediate time scale.

A third time scale is one in which the time unit is hours extending over an interval of one day to possibly one week's period. This time scale establishes a comparable spatial dimension. The spatial scale may, therefore, involve two and possibly three dimensional analyses. Typical problems addressed in this respect would be transient algae blooms, unexpected spills or discharges of pollutant mass from combined sewer overflows.

A wide variety of planning problems can be analyzed using steady state mathematical models which can provide the necessary spatial detail for important water quality variables. Certain phenomena can achieve steady state conditions within a short time interval and as such, can be modeled with relative ease. Examples of the phenomena which can be modeled on a steady state basis are the distribution of bacteria, dissolved oxygen concentrations, and nutrient distributions. These steady state representations are particularly useful because of the ease of model operation and ability to respond rapidly and relatively inexpensively to specific planning questions.

2.6.1.2 Hydrology and Climatology

The hydrology of the basin or metropolitan region, in particular the freshwater flow, is of considerable importance in mathematical modeling. This parameter determines not only the dilution which the sources of mass receive, but also the velocity at which they move downstream. The flow also affects some of the reaction coefficients.

The determination of the water temperature characteristics of the river sets the level of the reaction coefficients in any model related to bacterial or higher order biological activity and the saturation concentration of dissolved oxygen.

2.6.1.5 Hydrodynamics

The hydrodynamic properties of a body of water, for example, velocity, tidal characteristics, and turbulent diffusion, form the basic transport mechanisms which classify the body of water into one of several generic categories to be discussed below. The degree of detailed hydrodynamic information that is required is strongly dependent on the time and space scale of the problem under consideration.

River velocities can often be related to river flows by an exponential relationship (see section 2.3.5). If information is available which correlates velocity with flow (or depth with flow), this information can form a basis for predicting the velocity (or depth profile) regime in a river under different flow conditions.

Tidal velocities can often be obtained from the U.S. Coast and Geodetic Survey Tide and Current Tables, or from direct measurement. The net river flow in estuarine analysis also forms an important input into the mathematical model of estuarine systems. Flow records are often available for estuarine tributaries that would allow one to construct the net river flow regime at the head end of an estuary and downstream along its length. Flows due to incremental drainage area accretions can be readily estimated with data from upstream reaches, using the approach discussed in Section 2.3.3.

For large lakes and coastal waters, the hydrodynamic situation becomes increasingly more complex. Density stratification further adds to the difficulty of specifying the hydrodynamic circulation. For large and complex circulation patterns as in lakes, the hydrodynamic equations must be considered in determining water movements and subsequent pollutant distributions. However, some simplified techniques are available and are discussed in Chapter 5.

2.6.2 Model Classification of Natural Systems

The classification of natural water systems for water quality analysis is based primarily on the number of spatial dimensions which must be considered and on the mixing characteristics of the body of water.

2.6.2.1 Streams and Rivers

The simplest situation is a one-dimensional flowing stream or river where the mixing characteristics are such that the dispersion of the mass of material can be neglected in comparison to the flow. In this case, the river flow is the major mass transport mechanism. This simplification is significant in terms of computational complexity and the amount of information required for water quality analysis. The fundamental equation that governs the transport of material in a non-dispersive system for steady state and constant parameters is:

$$\frac{Q}{A}\frac{dc}{dx} = -KC + \frac{W}{A} \tag{2-6}$$

where:

c = concentration of substance of interest (mg/l)
t = time (days)
x = distance downstream (miles)
A = cross-sectional area (sq. ft.)
Q = river flow (cfs)
K = first-order decay coefficient (1/day)
w = distributed source of mass (lbs/day/mile)

For a complete specification, the initial concentration, the reaction rate, and the river flow and cross-sectional areas are required. For some variables, there may be a coupling effect where the solution of one equation feeds forward into a second equation and acts as an input. For example, the interaction between the biochemical oxygen demand and dissolved oxygen is represented by a coupled set of equations. For more complex reactants three, four or more equations may be required, all of which interact through reaction kinetics.

2.6.2.2 Estuaries

An estuary is defined here as that portion of a coastal river where the tidal action from the ocean is a significant hydrodynamic parameter. There are two broad sections of estuaries, the tidal river portion where the water body ebbs and floods but is entirely freshwater; and the lower estuarine portion where, in addition to the ebbing and flooding of the tide, a significant intrusion of sea salts occurs. One or two spatial dimensions, (e.g., the longitudinal and vertical dimensions) may be of importance in estuaries. The primary difference between estuaries and the one-dimensional river flow situation is the dispersive mass transport due to the tidal mixing occasioned by tidal flow reversals. This forms an important transport phenomena in addition to the net freshwater flow through the estuary and, as such, must be included specifically in the analysis.

Several methods are available to directly evaluate the dispersion coefficient (see Chapter 5).

2.6.2.3 Lakes and Reservoirs

Lakes and reservoirs can involve either two or three spatial dimensions. The flow regime in these bodies of water can be quite complex since there is usually no dominant mechanisms which determines the advective flow and mixing in contrast to the case of estuaries and rivers. The stratification which can occur due to the absence of intense advective or mixing forces, complicates the distribution of water quality constituents in a vertical direction. Thus, lakes and reservoirs can encompass a broad spectrum of complexity, ranging from completely mixed water bodies to highly stratified water bodies.

A number of attempts have been made to define the hydrodynamic regime associated with lakes, reservoirs and impoundments. In general, the mixing, turbulence and advection are due to winds, seiches, and density differences. From a practical planning standpoint, two options are open to modeling lakes and impoundments. It may be possible to apply some of the refined mathematical techniques which have been developed to evaluate the hydraulic regime as discussed in Chapter 5 and Appendix A. Alternatively, it may be possible and practical, depending on the water quality problem being addressed, to employ observed data and field measurements as an adequate assessment for the hydrodynamic circulations. As an example, it is possible to obtain data on the thermal stratification within the lake or impoundment and accept this as the basis for segmentation of a model of the lake. In addition, it is possible to inject dye into various areas of the lake and determine dispersion, mixing, and circulation patterns from an observation of the transport of dye within the lake.

2.6.2.4 Coastal Waters

Coastal waters encompassing tidal embayments and near shore coastal waters can require two or three-dimensional analyses. The techniques available for evaluation of the hydraulic regime in terms of circulation pattern, dispersional coefficients, etc., are essentially similar to those available for evaluation of these phenomena in lakes and in estuaries. Once again, the particular water quality problem being addressed will dictate the most effective method of developing an adequate understanding of the hydraulic circulation and mixing patterns.

For the preliminary impact analysis which follows, one-dimensional streams are used for illustration purposes. Streams are discussed in the following sections because of their ease of analysis. The calculations for a simple stream can be performed on a desk top calculator or a slide rule. It is understood that many of the 208 study areas include estuaries, lakes and coastal waters. For these more complex water bodies, the analyst will have to rely in the loading estimates and the modeling techniques presented and discussed in Chapter 5 and Appendix A. The solutions of the equations in estuary, lake and coastal modeling are much more complex and generally require computer solution techniques.

2.6.3. Stream Impact Analysis

The least complex receiving water body in terms of calculating the impact of wastewater discharges is a stream or river. The essentially one-dimensional character of the transport, together with the characteristically short time to reach equilibrium make possible the simplifying assumptions of one important spatial dimension and temporal steady state. The additional complexity of spatially varying hydraulic and geometric characteristics are approximated by analyzing the receiving water as a sequence of segments within which it is assumed that the hydraulic and geometric parameters are constants.

In a preliminary analysis, it is recommended that the stream be segmented into a maximum of five reaches. The purpose of segmenting the stream is to simplify the number of calculations required in the impact analysis and to keep the level of detail of the impact analysis consistent with accuracy of the load estimation. In general, stream segments are constructed for areas of approximately constant flow, cross-sectional areas, depths, and velocities. Additional segments are formed at the location of important point source load inputs. If less than five stream segments are required for the particular basin, then the analysis is more manageable.

For the hypothetical example, the South River is segmented into five stream segments as shown in Figure 2-17(b). The reaches are between Milepoints 0 and 5, 5 and 15, 15 and 20, 20 and 24, 24 and 33. Stream divisions are made at Milepoints 5 and 15 for geometry and flow changes. The divisions at Milepoint 20 and 24 are created for the municipal point source load input and the industrial point source load input.

The average geometry is previously summarized in Table 2-3 and the average flows are summarized in Table 2-16. In order to simplify the equations used in the preliminary stream impact analysis which follows, the average stream flow within the segment is used. This is an approximation of the actual flow which increases linearly from the beginning to the end of the stream reach. The average stream flow is defined as the flow at the beginning of the section plus the flow at the end of the section divided by two.

It should be noted that for the example summer storm analysis, the flow was defined as being constant throughout the study area. This simplification was made because of the large base flow and the variability of the rainfall and runoff coefficient during a short duration storm. Chapters 3 and 4 will provide details necessary to increment the stream flow runoff during a storm event.

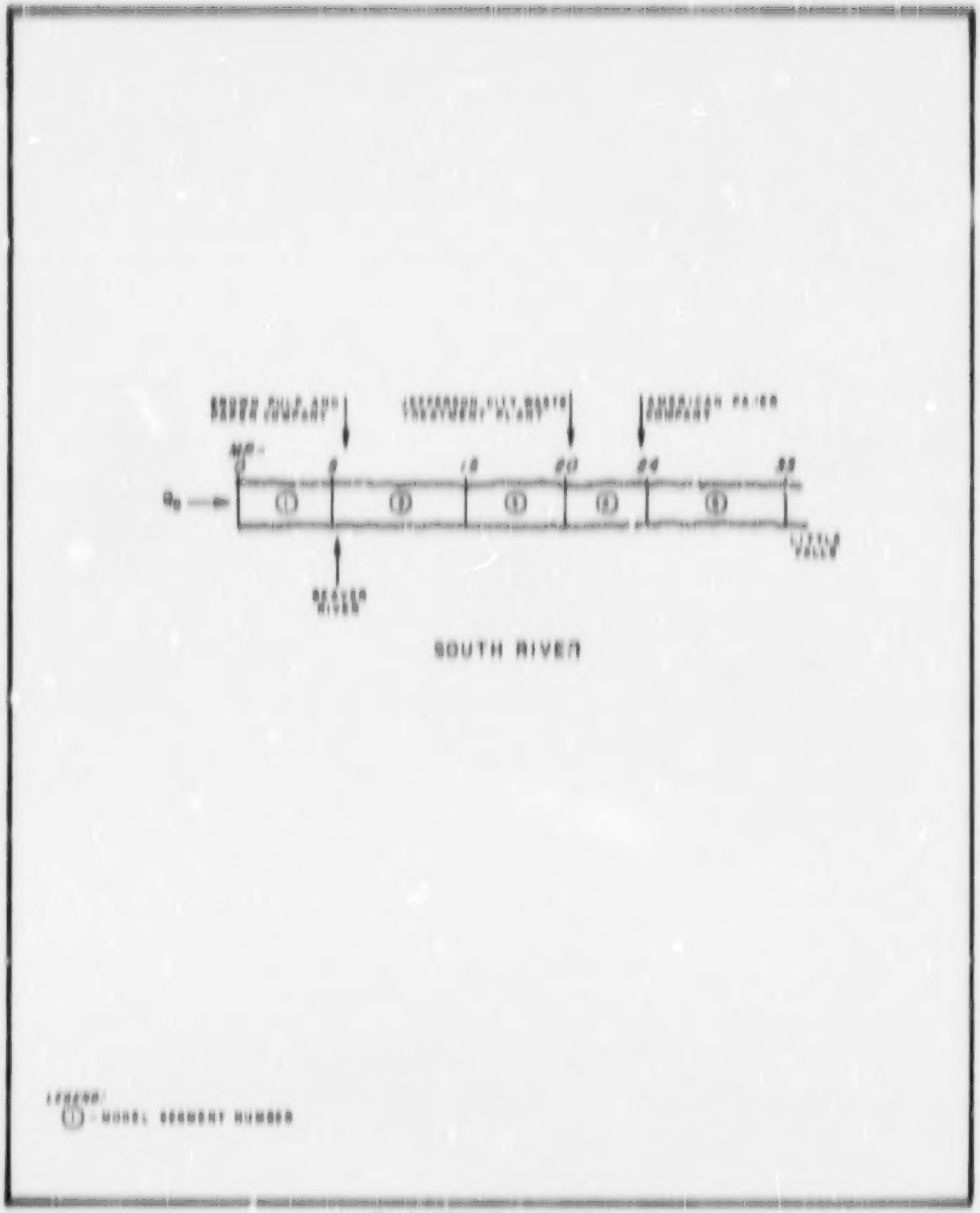


FIGURE 2-17(b)

MATHEMATICAL MODEL SEGMENTATION FOR THE HYPOTHETICAL SOUTH RIVER

TABLE 2-16

HYPOTHETICAL EXAMPLE

SUMMARY OF SOUTH RIVER FLOWS BY MODEL SEGMENT

Segment	Milepoint	Annual Average Flow (cfs)	Summer Flow (cfs)	Summer Low Flow (cfs)	Summer Storm Flow (cfs)
1	0	500 (535)	250 (268)	50 (54)	(1625)
	4.99	570	285	57	
2	5.0	820 (903)	410 (451)	82 (91)	(1625)
	14.99	985	492	99	
3	15.0	985 (1025)	492 (513)	99 (103)	(1625)
	19.99	1065	533	107	
4	20.0	1065 (1088)	533 (544)	107 (109)	(1625)
	23.99	1110	555	111	
5	24.0	1110 (1160)	555 (580)	111 (116)	(1625)
	33.0	1210	605	121	

( ) = average flow in segment

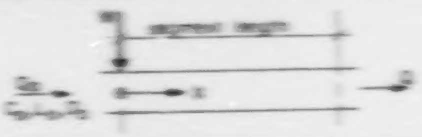
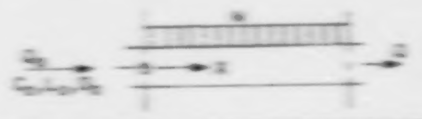
2.6.3.1. Method of Analysis

For the preliminary analysis, all in-stream concentrations are calculated from equations based on the principle of conservation of mass under steady state conditions. Critical seasonal effects are estimated by assuming constant waste and stream characteristics for the particular season. Concentrations will be assumed to be constant throughout the depth and across the width of the receiving water. The receiving water geometry is, therefore, approximated by a series of constant geometry and constant flow segments. The governing differential equations for the receiving water concentrations are linear so that the effects of the individual waste sources (point, agricultural, forest, etc.) can be calculated separately and, at a given location, added together to give the total in-stream concentration. In summary, a spatial one-dimensional steady state analysis is performed in order to calculate the distributions of a receiving water constituent throughout the length of the stream in the 208 study area. Constituents to be analyzed are grouped into three categories: conservative, single reactant and coupled sequential reactants.

2.6.3.2. Conservative Constituents

Conservative constituents are those that are not subject to reactive change and remain dissolved or suspended in the stream. For the present, it is assumed in subsequent analyses that total nitrogen, total phosphorus and total suspended solids fall into this category on an annual average basis.

The solutions to the governing linear differential equation for both point and distributed sources are shown in Table 2-17. Note that the spatial coordinate x is in the direction of flow and that it is reset to x = 0 at the upstream end of each segment. The constant Co is the in-stream concentration at x = 0 due to waste sources entering segments of the river upstream of the segment under consideration. It is calculated by summing up all upstream waste inputs and dividing the sum by the flow at x = 0. Incremental increases in concentrations due to wastes entering the segment being analyzed are evaluated by the term W/Q for the point sources and wx/Q for the distributed sources where W is the point source mass discharge rate (pounds/day) and w is the distributed mass discharge

	POINT SOURCE	DISTRIBUTED SOURCE
	 W segment length Q_0 C_0, L_0, D_0 0 X Q	
Conservative C	$C = C_0 + W/Q$	$C = C_0 + wX/Q$
Reactive L	$L = L_0 e^{-K_r X/U} + (W/Q) e^{-K_r X/U}$	$L = L_0 e^{-K_r X/U} + \frac{w}{A K_r} [1 - e^{-K_r X/U}]$
Coupled D	$D = D_0 e^{-K_a X/U}$ $+ L_0 \cdot \frac{K_d}{K_a - K_r} [e^{-K_r X/U} - e^{-K_a X/U}]$ $+ (W/Q) \cdot \frac{K_d}{K_a - K_r} [e^{-K_r X/U} - e^{-K_a X/U}]$	$D = D_0 e^{-K_a X/U}$ $+ L_0 \cdot \frac{K_d}{K_a - K_r} \cdot [e^{-K_r X/U} - e^{-K_a X/U}]$ $+ \frac{w}{A K_r} \cdot \frac{K_d}{K_a - K_r} (\frac{K_r}{K_a} e^{-K_a X/U} - e^{-K_r X/U} + \frac{K_a - K_r}{K_a})$

NOTE:

Q = FLOW
X = DISTANCE
C = CONSERVATIVE SUBSTANCE CONCENTRATION
L = REACTIVE SUBSTANCE CONCENTRATION (BOD)
D = COUPLED SUBSTANCE CONCENTRATION (D.O. DEFICIT)
U = VELOCITY
A = CROSS-SECTIONAL AREA

K_r = BOD REMOVAL COEFFICIENT
K_d = BOD OXIDATION COEFFICIENT
K_a = D.O. REAERATION COEFFICIENT
C_0, L_0, D_0 = CONCENTRATION AT X=0
W = POINT SOURCE LOADING RATE
w = NON-POINT SOURCE LOADING RATE

TABLE 2-17

SUMMARY OF SOLUTIONS FOR POLLUTANT CONCENTRATIONS IN THE RECEIVING WATERS rate (pounds/mile/day) and x is distance (miles). Concentrations within the segment increase linearly due to distributed sources.

Since there are no removal or growth mechanisms involved, the analysis of conservative substances reduces to a simple additive calculation of accumulating waste loads, by source (point, agriculture, etc.) and dividing the cumulative source total by the appropriate flow. This procedure is illustrated in Table 2-18 for calculating total nitrogen concentrations due to agricultural sources. Repeating this procedure for all sources results in the estimate of the annual average concentrations of a conservative substance in the river. The technique for calculating the total nitrogen concentrations for all sources is illustrated in Figure 2-18. Annual flow is plotted. Then, cumulative waste loadings by source are generated and receiving water concentrations are determined as the quotient of the load and flow. For example, the cumulative total nitrogen loading entering model segment 4 at Milepoint 20 is approximately 7,500 lbs/day. Dividing this by the flow of 1,065 cfs and a conversion factor of 5.4 results in a concentration of 1.35 mg/l, as plotted in the Figure 2-18. Of this total, agricultural sources contribute 0.57 mg/l due to cumulative loads of 3,150 lbs/day and the effluent from the municipal sewage treatment plant (2,135 lbs/day) contributes 0.38 mg/l.

2.6.3.3. Reactive Constituents

Reactive constituents are subject to change within the receiving water due to physical, chemical and biological reactions. The variables included in the preliminary analysis framework that fall into this category are BOD, coliform bacteria and nutrients. For reactive substances, the critical season is usually the low flow, high temperature period of the year. Therefore, the analysis is performed for that period. Although total nitrogen and phosphorus are treated as conservative on an annual average basis, they are considered reactive during the summer low flow period due to algal uptake of the nutrients and subsequent removal by settling.

TABLE 2-18

HYPOTHETICAL EXAMPLE

EXAMPLE CONSERVATIVE SUBSTANCE IMPACT CALCULATION TABLE AGRICULTURAL NON-POINT SOURCE LOADS

Section Number	River Mile-Point	T-N[a] added (lbs/day)	T-N Cummulative (lbs/day)	Q[b] Cummulative (cfs)	Total Nitrogen Concentration (mg/l)
1	0	0	0	500	0
	4.99	450	450	570	0.15
2	5.0	0	450	820	0.10
	14.99	1950	2400	985	0.46
3	15.0	0	2400	985	0.46
	19.99	750	3150	1065	0.57
4	20.00	0	3150	1065	0.57
	23.99	324	3474	1110	0.59
5	24.0	0	3474	1110	0.59
	33.0	729	4203	1210	0.65

(a)T-N added = T-N (lbs/day/mi) x length(mi)

[b] Annual average flows

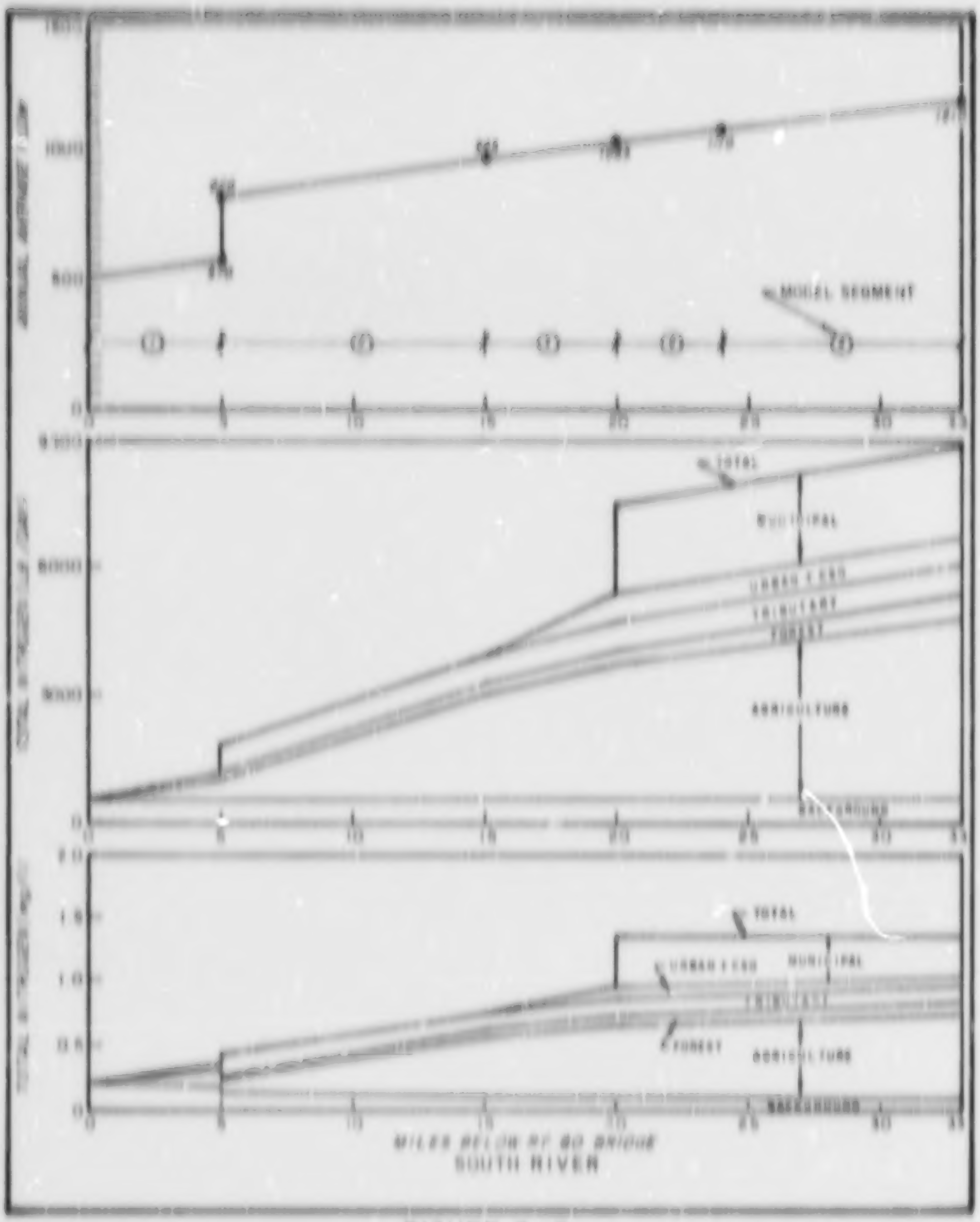


FIGURE 2-18
INSTREAM TOTAL NITROGEN CALCULATION
(ANNUAL AVERAGE FLOW)
HYPOTHETICAL EXAMPLE

Decay mechanisms occur for each of these constituents and first order kinetics are assumed to be applicable. Representative reaction rates for these constituents are indicated in Table 2-19. The BOD reaction rates are particularly applicable to the carbonaceous fraction but, in the preliminary analysis, the rate is also considered appropriate for the nitrogenous oxygen demand. The nutrient removal rates are generally applicable to conversion to other nutrient forms, but the lower range also applies to estimated first order algal settling.

TABLE 2-19

RANGE OF VALUES OF REACTION COEFFICIENTS IN STREAMS
(REF. 6)

Substance	K_r (per day)[(a)]
Coliform Bacteria	1 - 5
BOD_5	0.2 - 2.0
Nutrients	0.1 - 1.0

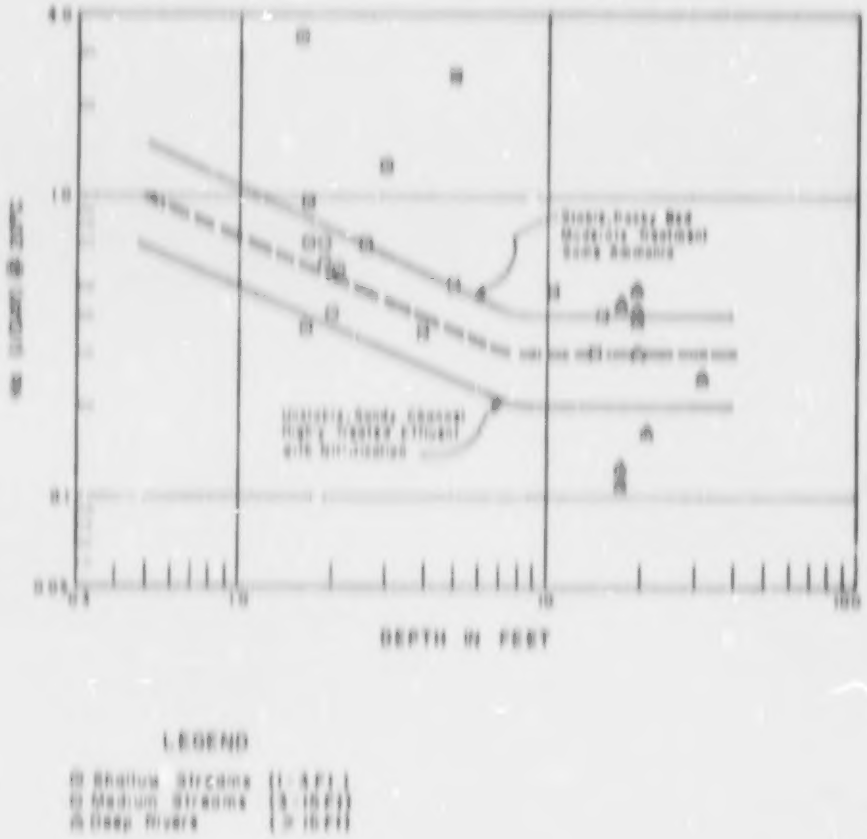
[(a)] Base e, 20°C

The coefficients in Table 2-19 are for water temperatures near 20°C. For preliminary estimates, temperature corrections can generally be ignored. Where appropriate conversion to other temperatures can be made by:

$$K_r(T) = K_r(20)(1.047)^{T - 20} \qquad (2-7)$$

where $K_r(T)$ is the reaction coefficient at temperature, T(°C), and $K_r(20)$ is the reaction coefficient at 20°C.

In this preliminary analysis, the BOD_5 reaction coefficient (K_r) accounts for both the oxidation and the settling of BOD_5. In the dissolved oxygen analysis which follows, the BOD_5 oxidation rate is assumed as being equal to the BOD_5 removal rate. Therefore, there is no settling of BOD_5. An estimate of the BOD_5 oxidation rate can be made using the information in Figure 2-19(a). This Figure relates the oxidation rate to the stream depth and is based on data collected during many stream studies.



SOURCE (6)

FIGURE 2-19 (a)
OXIDATION COEFFICIENT (Kd) AS A FUNCTION OF DEPTH

Receiving water concentrations caused by point and distributed sources are calculated from the solutions cited in Table 2-17 for reactive substances. The form of the solution is similar to that for conservative constituents where the first term represents the effects of upstream loads and the second term represents the impact of point or distributed sources entering the segment being analyzed. In the first term, the constant L_0 represents the residual concentration at $x = 0$ due to all upstream sources and the exponential accounts for decay of L_0 throughout the segment being analyzed. The symbol e is the base of natural logarithms (2.718). K_r is the decay rate at the summer water temperatures and U is the average low flow water velocity in the segment ($U=Q/A$ = average flow/cross-sectional area). In some cases, time of travel data will be available and should be used for the calculation of freshwater velocity. Measured time of travel data provides the analyst with accurate stream transport information and should be used instead of the calculated freshwater velocity (Q/A). In this preliminary analysis, the reaction rate for each constituent is assumed constant for all waste sources and for all segments. Refinements to this procedure are discussed in subsequent chapters. The second term of the reactive point source solution is similar in behavior to the first term, with W/Q analogous to L_0. The maximum effect occurs at $x = 0$ and then decreases in the downstream direction. For distributed reactive waste inputs, there is no stream impact at $x = 0$ and a build-up of concentration occurs downstream, with a maximum possible value to $w/(A.K_r)$, as x approaches infinity.

Sample calculations for five-day BOD are contained in Table 2-20 for the summer low flow period. As indicated in the Table, the average flow, cross-sectional area and stream velocity are first determined together with the appropriate temperature-adjusted reaction rate. The initial concentration due to upstream sources (L_0) is then calculated from a mass balance at $x = 0$. Aggregated point and distributed sources are then entered. Substitution of the above data into the solutions presented in Table 2-17, results in a spatial distribution of five-day BOD within the segment being analyzed. Similar computations follow for subsequent segments.

TABLE 2.20

HYPOTHETICAL EXAMPLE
REACTIVE CONSTITUENT (BOD_5) SIMPLE IMPACT CALCULATION

[illegible] LOW FLOW ANALYSIS

SEGMENT 1 - MILEPOINTS 0.0 to 5.0

Q = 268 cfs

A = 766 sq. ft.

U = (Q/A) · (16.36) = 7.75 mi/day

K_r = 0.3 @ 20°C & 0.377/day @ 25°C

L_u = UPSTR. BOD_5 = 1.0 mg/l

L_0 = $(L_u) \cdot (Q_u/Q_1) = (1.0) \cdot (250/268)$ = 0.933mg/l

W = 0

w = 304 lb/mi·day (AG + FOR)

Rewriting Equations of Table 2.17 with conversion factors for units:

$$L(x) = L_0 e^{-K_r x/U} + (W/5.39Q)\, e^{-K_r x/U} + (1.01 \cdot w/(A \cdot K_r)) \cdot (1 - e^{-K_r x/U})$$

For x = 1 mi;

$$L(1) = 0.933\, e^{-0.377(1)/7.75} + 0 + (304 \cdot 1.01/(766 \cdot 0.377))\,(1 - e^{-0.377(1)/7.75})$$

$$L(1) = 0.889 + 0 + 0.201 = 1.09 \text{ mg/l}$$

For x = 5.0 mi;

$$L(5.0) = 1.667 \text{ mg/l}$$

SEGMENT 2 - MILEPOINTS 5.0 to 15.0

Q = 451 cfs

A = 990 sq. ft.

U = 7.45 mi/day

K_r = 0.377/day

L_0 = (1.667) · (268/451) = 0.991 mg/l

W = 1441 lb/day (trib. & indust)

w = 540 lb/mi·day (AG & FOR)

For MP 5; x = 0; $L(0) = 0.991\, e^{-0.377(0)/7.45} + (1441/(451) \cdot (5.39))\, e^{-0.377(0)/7.45}$

$$+ (540 \cdot (1.01/(990 \times 0.377)))(1 - e^{-0.377(0)/7.45})$$

$$L(0) = 0.991 + 0.594 + 0.00 = 1.59 \text{ mg/l}$$

$$L(15.0) = 2.704 \text{ mg/l}$$

Procedure repeated for segments 3, 4, and 5.

The procedure is suitable for an ultimate BOD analysis (carbonaceous and nitrogenous) as well as for coliform bacteria and summer nutrient analyses. Relative effects of each point source and each distributed source (by land use type) are easily determined by substitution of the single source of interest in the appropriate segment(s). The procedure can be tedious and use of a programmable calculator is recommended.

2.6.3.4 Sequentially Reacting Constituents

Sequential reactants occur if the growth or removal of the initial constituent causes changes in a second constituent. For the preliminary analysis, the initial substance being considered is ultimate oxygen demand (UOD) and dissolved oxygen deficit is the second substance. Thus, the removal of UOD causes an uptake of oxygen and an increase in the DO deficit of the stream. The deficit itself is reduced through reaeration. Stream dissolved oxygen concentrations are calculated by deducting the DO deficits from the temperature-dependent saturation concentration. Since saturation levels are lowest during the summer high temperature periods, and reaction rates are highest, analyses for dissolved oxygen will be carried out for summer low flow, drought flow and storm flow conditions. Curves of dissolved oxygen saturation concentrations versus temperature are shown in Figure 2-19(b).

As mentioned above, the ultimate oxygen demand from waste sources (carbonaceous and nitrogenous BOD) will be considered as the source of DO deficit. A single reaction rate will be used for both components and confirmatory analyses to determine whether nitrification occurs will be discussed in Chapter 5. For the preliminary analysis, the removal rate of UOD (K_r) will be set equal to the uptake rate of oxygen (K_d), which assumes that settling of the BOD is insignificant. Reaeration coefficients (K_a) will be calculated from the O'Connor-Dobbins formulation (Reference 40)

$$K_a = 12.96\ U^{1/2} / H^{3/2} \quad @\ 20^{\circ}C \qquad (2\text{-}8)$$

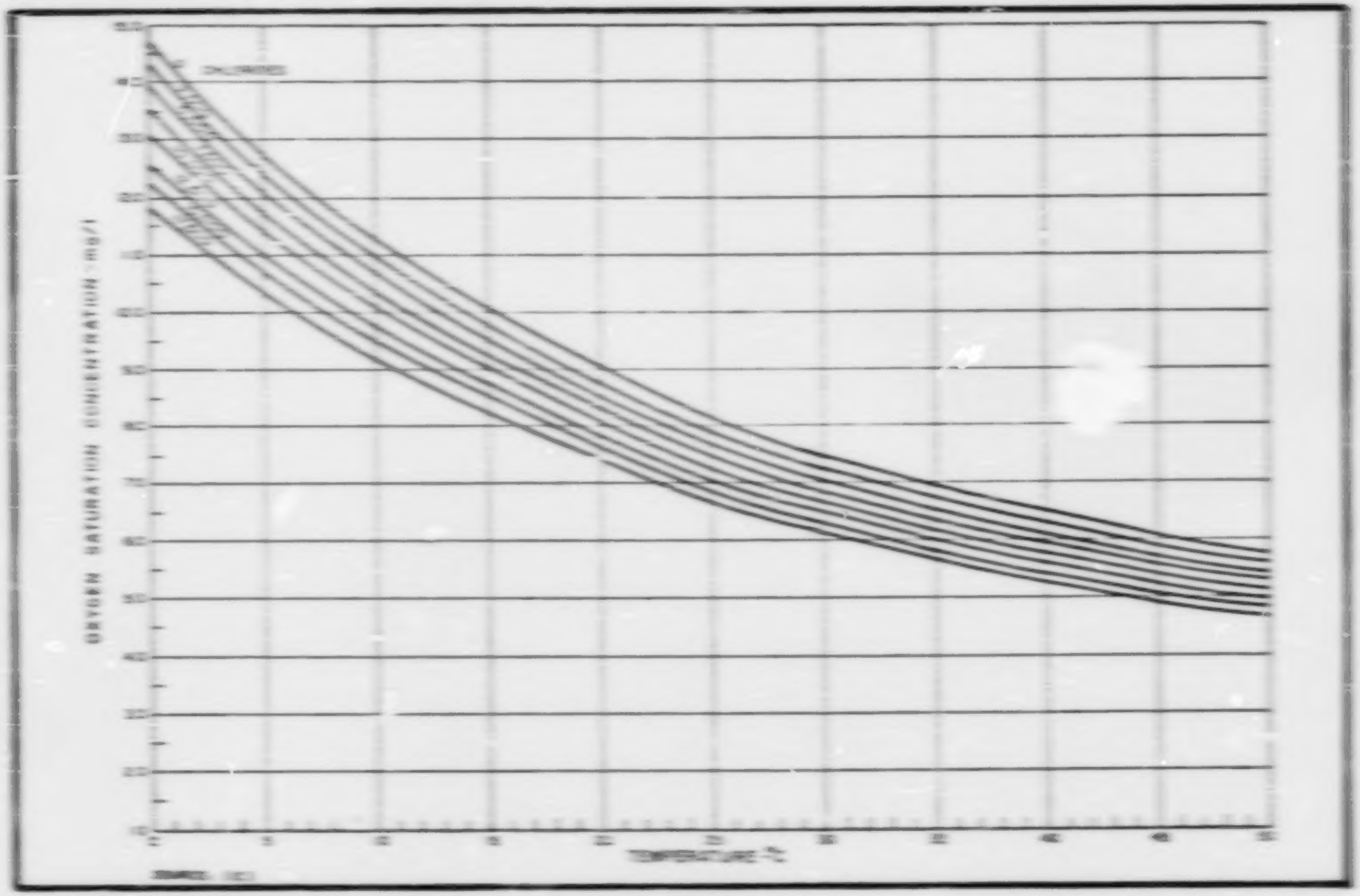


FIGURE 2-9 (b)
D.O. SATURATION - TEMPERATURE - CHLORIDE RELATIONSHIP

where U is the average stream velocity in ft/sec and H is the water depth in feet. When necessary, temperature corrections can be made using:

$$K_a(T) = K_a(20)\ (1.024)^{T-20} \qquad (2\text{-}8)$$

Figure 2-20 is an alternate method useful for estimating the reaeration coefficient where $K_a = K_L/H$ and K_L is the surface transfer rate (ft/day). This Figure shows the range of measured values together with the curves representing the theoretical formula.

The effect of benthal demands and the daily averaged algal effect are not included and should be included in a more refined analysis if appropriate.

Dissolved oxygen deficits in the stream are calculated from the equations in Table 2-17 which contain the reaction rates K_a, K_r and K_d discussed above. The symbol D represents the deficit, D_0 is the deficit at x = 0 due to all upstream sources of UOD, and L_0 is the residual concentration of UOD at x = 0 due to the upstream sources. The third terms of the equation, beginning with W/Q and $w/A \cdot K_r$, represent the effects of the point and distributed sources of UOD entering the segment under analysis.

Sample calculations for the dissolved oxygen analysis under summer low flow conditions are contained in Table 2-21. For the first segment, average geometry and flow information (Q, A, H) for the segment is entered, and the average velocity is calculated. The assumed reaction rate of the UOD is temperature corrected to 25°C. The reaeration rate is then calculated for the velocity and depth of the segment and adjusted for the temperature of 25°C. Initial deficit from upstream sources is flow-adjusted to D_0 = 0.93 mg/l. For carbonaceous BOD, the initial in-stream concentration (L_0) is calculated and the magnitudes of the BOD_5 point and distributed loads entered. Similar entries are made for the nitrogenous BOD constituent. Note that the agricultural and forest nitrogen loads are considered to be non-reactive since much of this input is either slowly reacting or in the inorganic (nitrate) form. The initial BOD_5 concentration and loadings are then expressed as UOD by scaling the BOD_5 by 1.5 (an estimate of the ratio of ultimate carbonaceous

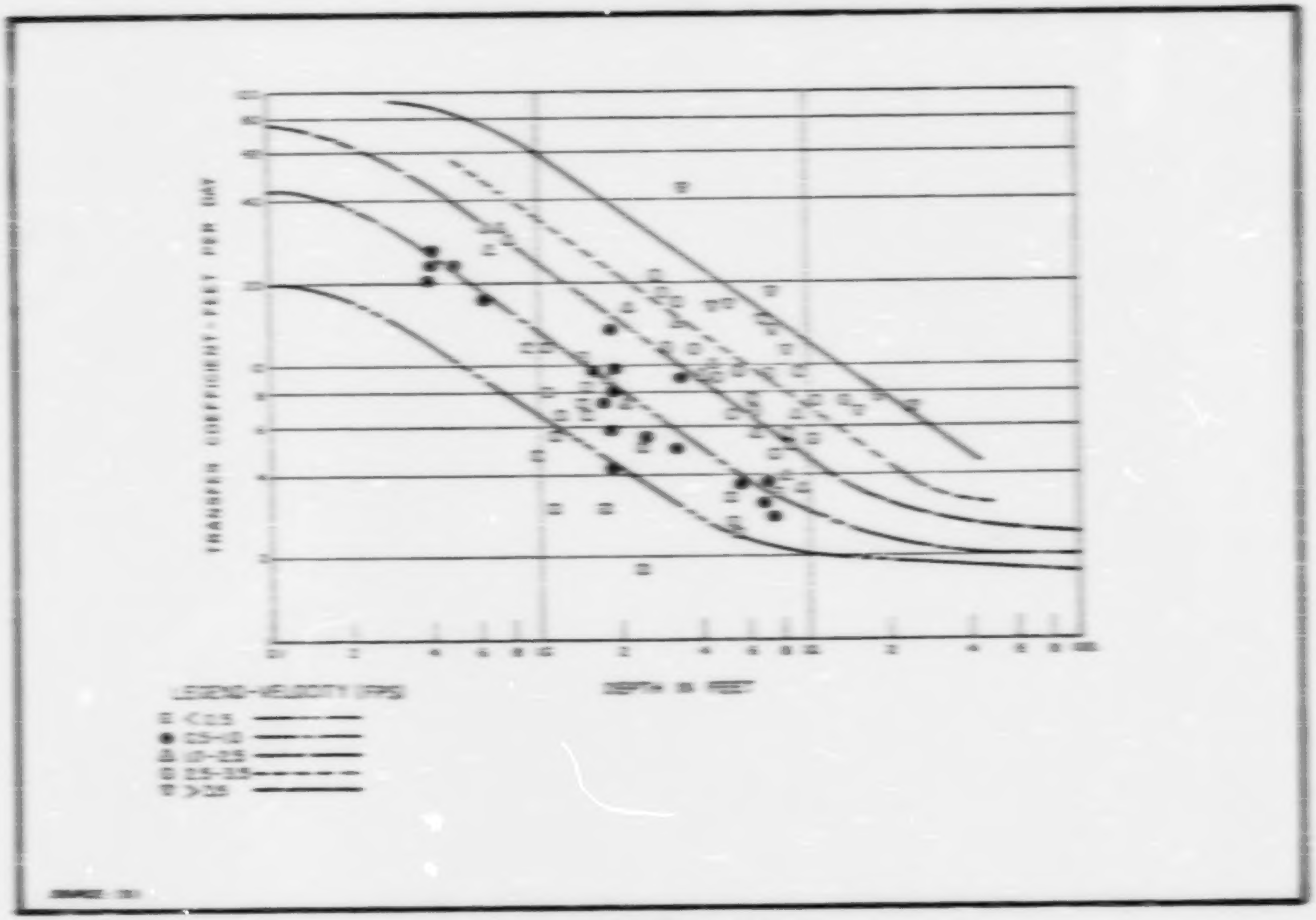


FIGURE 2-20

TRANSFER COEFFICIENT (K_L) AS A FUNCTION OF DEPTH

TABLE 2-21
COUPLED CBOD - DO STEADY STATE CALCULATION
LOWER FLOW ANALYSIS
HYPOTHETICAL SOUTH RIVER EXAMPLE

= =

SEGMENT 1 : MILEPOINTS 0.0 to 5.0

Q = 268 cfs
A = 566 sq. ft.
H = 2.3 ft.
U = (Q/A) · 16.36 = 7.75 mi/day
K_r = 0.3 @ 20°C & 0.377 @ 25°C

K_d = K_r = 0.377 @ 25°C
K_a = $12.96\ U^{1/2}(\text{ft/sec})/H^{3/2}(\text{ft})$ @ 20°C
K_a = $12.96(0.47^{1/2}/2.3^{3/2})$ = 2.555 1/day
K_a = $2.555\ (1.024^{25-20})$ @ 25°C = 2.877 1/day

DEF : $D_0 = (D_u) \cdot Q_u/Q_1 = (1.0) \cdot$ [illegible]$/268 = 0.032$ mg/l
CBOD : $L_0 = (L_u) \cdot Q_u/Q_1 = (1.0) \cdot$ [illegible]$/268 = 0.032$ mg/l
$W = 0$
w = 303 lb/mi-day (AS 5 FOR)
NBOD : $L_0 = 0$
$W = 0$
w = 0 (AS 5 FOR assuming non-reactive)
UOD : $L_0 = (0.93) \cdot 1.5 + (0) \cdot 4.57 = 1.40$ mg/l
$W = 0$
$w = (303) \cdot 1.5 + (0) \cdot 4.57 = 456$ lb/mi-day

= =

Rewriting equations of Table 2-17 with conversion factors for units:

$$D(x) = D_0\, e^{-K_a x/U} + L_0 \cdot \frac{K_d}{K_a - K_r}\left(e^{-K_r x/U} - e^{-K_a x/U}\right) + (W/Q \cdot 5.39) \cdot \frac{K_d}{K_a - K_r} \cdot \left(e^{-K_r x/U} - e^{-K_a x/U}\right)$$

$$+ \left(\frac{w}{A\,K_r}\right) \cdot \frac{K_d}{K_a - K_r} \cdot 5.04 \cdot \left(\frac{K_r}{K_a}\, e^{-K_a x/U} - e^{-K_r x/U} + \frac{K_a - K_r}{K_a}\right)$$

For x = 1 mi;

$$D(1) = 0.032\, e^{-2.8(1)/7.75} + (1.40) \cdot \frac{0.377}{2.877 - 0.377}\left(e^{-0.377(1)/7.75} - e^{-2.877(1)/7.75}\right) + 0$$

$$+ \left(\frac{456}{566 \cdot 0.377}\right) \cdot \left(\frac{0.377}{2.877 - 0.377}\right) \cdot 5.04 \cdot \left(\frac{0.377}{2.877}\, e^{-2.877(1)/7.75} - e^{-0.377(1)/7.75}\right.$$

$$\left. + \frac{2.877 - 0.377}{2.877}\right)$$

$D(1)$ = 0.643 + 0.056 + 0 + .003 = 0.702 mg/l
DO = $C_s - D(1)$ = 8.17 - 0.702 = 7.47 mg/l

$D(4.99)$ = 0.38 mg/l
DO = 7.78 mg/l

= =

TABLE 2-21
(Continued)

COUPLED (BOD - DO) SAMPLE IMPACT CALCULATION

SUMMER FLOW ANALYSIS

= =

SEGMENT 2 - MILEPOINTS 5.0 - 15.0

Procedure repeated for Segment 2

$D(5.00) = 0.50$ mg/l $Q_2 = 851$ cfs

DO = 7.67 mg/l

$D(14.99) = 0.92$ mg/l $L(14.99) = 2.70$ mg/l

DO = 7.24 mg/l

= =

SEGMENT 3 - MILEPOINTS 15.0 - 20.0

Q = 513 cfs
A = 990 ft²
H = 5.8 ft
U = (Q/A) · 16.35 = 8.48 mi/day

$k_1 = k_d = 0.3$ @ 20°C = 0.377 @ 25°C
$k_a = 12.86\ (.535)^{1/2}/(5.8)^{3/2} = 1.26$ @ 20°C
$k_a = 1.40$ 1/day @ 25°C

= =

CBOD: L_0 = upstream BOD = $(2.70) \cdot \frac{851}{913} = 2.87$ mg/l
W = 0
w = 1961 lbs/mi-day

NBOD: L_0 = upstream oxidizable nitrogen = 0
W = 0
w = 136 lbs/mi-day

UOD:

$L_0 = (2.37) \cdot 1.5 = 3.56$ mg/l
$w = (1961) \cdot 1.5 + (136) \cdot 4.57 = 3608$ lb/mi-day
W = 0

DEF: $D_0 = (0.92) \cdot \frac{851}{913} = 0.81$ mg/l

= =

At mile 15 x = 0, $D_0 = 0.81$

At mile 17 x = 2, $D(2) = 0.81\ e^{-1.42(2)/8.48} + (3.56) \cdot \left(\frac{0.377}{1.42-0.377}\right)\left(e^{-0.377(2)/8.48} - e^{-1.42(2)/8.48}\right) + 0$

$$+ \left(\frac{3608}{990 \cdot 0.377}\right) \cdot \left(\frac{0.377}{1.42-0.377}\right) \cdot (5.04) \cdot \left(\frac{0.377}{1.42}\ e^{-1.42(2)/8.48} - e^{-0.377(2)/8.48} + \frac{1.42-0.377}{1.42}\right)$$

D(2) = 0.58 + 0.75 + 0 + 0.11 = [illegible] mg/l
DO = 8.17 - [illegible] = 7.2[illegible] mg/l

D(19.99) = 1.35 mg/l, D.O = 6.82 mg/l

Procedure repeated for Segment 4, and 5

= =

BOD to BOD_5). The ratio of ultimate CBOD to BOD_5 is not always equal to 1.5 and the ratio varies depending on the components in the wastewater. Therefore, if a measured value is available for the different waste loads in the system, this ratio should be used in the preliminary input analysis. The nitrogenous oxygen demand can be approximated by multiplying the reduced nitrogenous constituents (organic nitrogen and ammonia) by 4.57, which is the mass of oxygen in pounds required to completely oxidize one pound of ammonia. Total kjeldahl nitrogen measures both ammonia-N and organic-N. The organic-N fraction is assumed to oxidize as ammonia does.

Substitution of the above data into the equation for coupled constituents (Table 2-17), allows calculation of dissolved oxygen deficits at any location in segment 1. Subtraction of the deficits from the saturation concentration of 8.17 mg/l at 25°C (Figure 2-21) results in the predicted dissolved oxygen concentrations. This procedure is then repeated for downstream segments, as illustrated for segment 3 in Table 2-21.

Effects of individual waste sources on the dissolved oxygen deficit are then determined by inputting each source into the equations and calculating resulting deficit concentration profiles. Programmable calculators are quite helpful to reduce the time required for these calculations.

2.7 Illustration and Interpretation of Preliminary Impact Analysis

The simple methodology presented in the impact analysis section of this chapter is applied to total nitrogen, total phosphorus, dissolved oxygen, total coliform bacteria and total suspended solids. Spatial distributions of these constituents are calculated using the available data and the cited literature estimates. Since the preliminary impact analysis is performed using estimated loading information, it should be recognized that the analysis is as accurate as the estimated numbers used in the analysis. Three-fold or more changes in computed concentrations in the receiving water can result if either significant loads or receiving water characteristics (e.g., reaction rates) are in error. However, this uncertainty is inherent in any preliminary assessment which relies

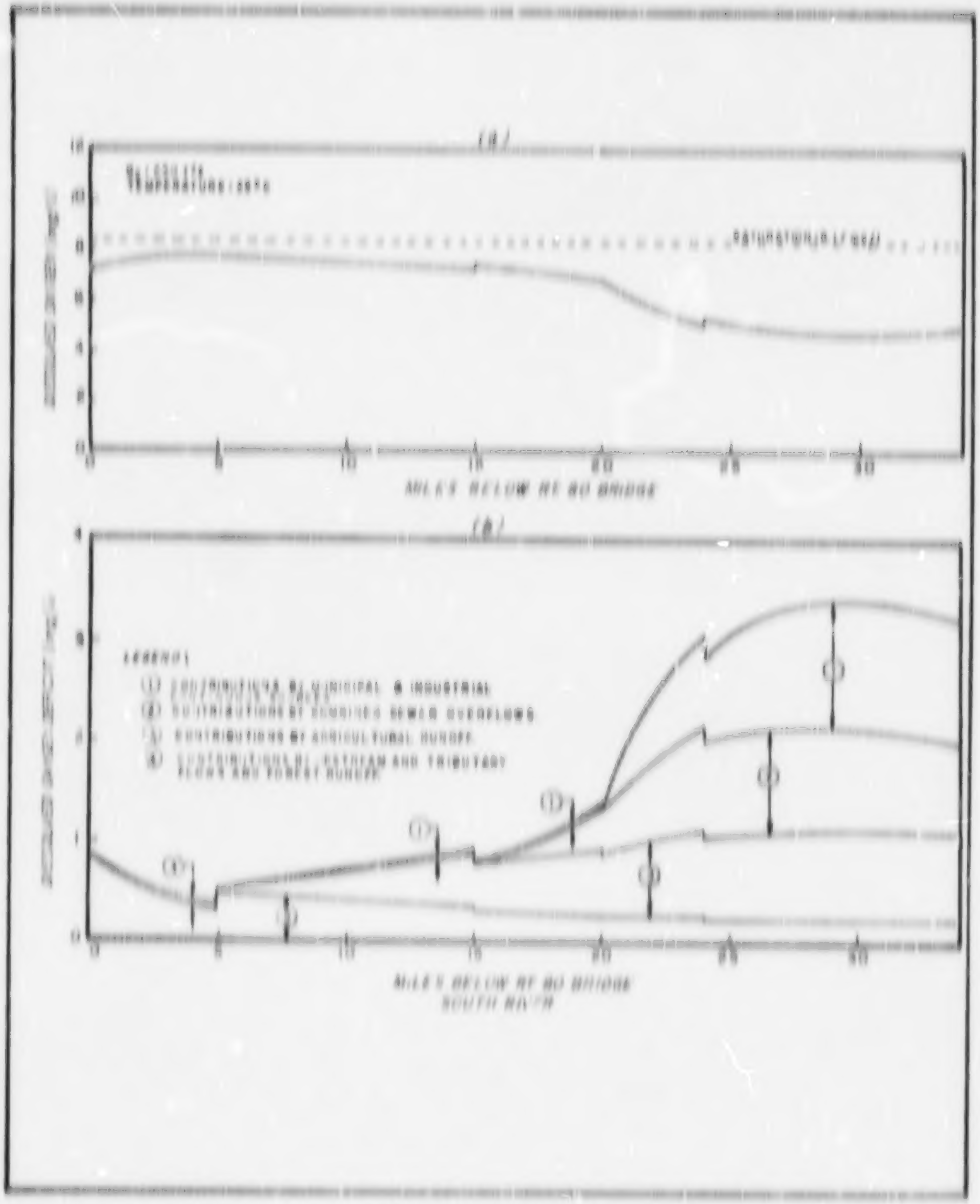


FIGURE 2-21
COMPUTED ESTIMATES OF DISSOLVED OXYGEN DISTRIBUTIONS
(SUMMER AVG. FLOW) AND COMPONENT D.O. DEFICIT DISTRIBUTIONS
HYPOTHETICAL EXAMPLE

on average conditions and rule-of-thumb estimates. Its utility is not diminished by these uncertainties, rather the results of the calculations should be interpreted with the limitation clearly in mind. For each type of analysis, a suggested set of rules is given in order to place the calculations in proper perspective. Available water quality data can also be used to assess the accuracy of the analysis and to correct gross inconsistencies.

2.7.1 Dissolved Oxygen Analysis

2.7.1.1 Summer Average Flow

Summer is generally the critical period for stream dissolved oxygen levels. Low river flows reduce the dilution of point and non-point source loads and high river temperatures increase reaction rates and reduce the dissolved oxygen saturation level thereby lessening the assimilation capacity of the river. Impact analyses are presented for average summer flow conditions and the minimum average 7-consecutive-day, one-in-ten-year, low flow.

First, if there is sufficient data, the observed dissolved oxygen data is compared with the stream standards to determine if there is a problem at summer flows and drought flows. This preliminary comparison is performed before the impact analysis. If the observed dissolved oxygen levels are well above the standards (no violations), then the impact analysis for dissolved oxygen is not performed. However, if the observed data is marginal with respect to the standards or violates the standards or if no pertinent data is available, then the impact analysis is necessary.

The interpretation of the preliminary analysis is based on an assessment of the reliability of the calculation and is shown in Table 2-22.

TABLE 2-22

DISSOLVED OXYGEN ANALYSIS

If Calculated Dissolved Oxygen Deficit (%)	Probability of a D.O. Problem
Less than 0.2	Improbable
0.2 to 2.0	Possible
2.0 to 10.0	Probable
greater than 10.0	Highly Probable

For the latter categories further analysis is required.

Figure 2-21(a) shows the calculated dissolved oxygen distribution for the hypothetical South River during the month of July 1975. The solid line in this figure is the calculated dissolved oxygen profile. During July 1975, the flow at the Route #9 Bridge was 250 cfs and the average stream temperature was 25°C. The BOD oxidation rate of 0.3/day is temperature corrected to 25°C and used along with the annual average point and non-point source loads to calculate the dissolved oxygen profile. Figure 2-21(b) shows the component dissolved oxygen deficit responses to all point and non-point source loads. The point sources loads (municipal and industrial), the combined sewer overflows and the agricultural runoff loads each produce about 1.0 mg/l of dissolved oxygen deficit between Milepoints 25 and 33. The contribution of the upstream deficit, tributary deficit, and forest runoff at the point of maximum deficit (Milepoints 25 to 33) is 0.25 mg/l. Based on this analysis, the net effect of all load sources is in the order of 3 mg/l dissolved oxygen deficit. It is, therefore, probable that a DO problem exists in the South River. Data collection efforts and further analysis should be directed towards definition of the oxygen demanding materials originating from the municipal and industrial loads, the combined sewer overflows, and the agricultural runoff. Instream, water quality data collection should be instituted in the region of calculated low dissolved oxygen concentration.

2.7.1.2 Summer Storm Flow

In the preliminary summer storm flow analysis, the combined sewer overflows, urban runoff, and municipal waste treatment plant loads are the major loads. Any increase in loads during storm events, such as a change in upstream water quality and agricultural runoff, cause only minor dissolved oxygen depressions because of the high stream flow rate.

For the hypothetical South River drainage basin, the review of the hydrological data, as discussed in Section 2.3.3, shows the long duration storm selected raised the stream flow by a factor of 3.2 times the annual average flow. This results from a 3 to 5-day storm event with rainfall of 7 times the annual average rainfall. Therefore, the annual average combined sewer loads are increased by a factor of 7 to reflect the increase in intensity when compared to $\bar{T}_1$. The dissolved oxygen deficit response to the combined sewer overflows, urban runoff and waste treatment plant is presented in Figure 2-22.

The maximum deficit produced by the combined sewer overflows and urban runoff is 3.8 mg/l which indicates a probable problem. The combined overflows are the largest contributors of oxygen demanding material to the South River, therefore, additional efforts should be directed towards the collection of site specific data and refining the loading contribution of the combined sewer overflows during this type of storm event.

2.7.1.3 Drought Flow

The drought flow dissolved oxygen profile can be computed as well. Since surface runoff is responsible for the transport of the non-point source loads and since surface runoff is minor during a drought period, only the point sources are used in the impact analysis.

For the hypothetical South River 208 study, the point source loads, both municipal and industrial and the upstream BOD and oxygen deficit, are the only oxygen demanding materials reaching the South River. The summer drought flow is 50 cfs at the Rt. 80 bridge and the stream temperature is 25^{0}C. The deficit response (Figure 2-23(b)shows that oxidation of the UOD

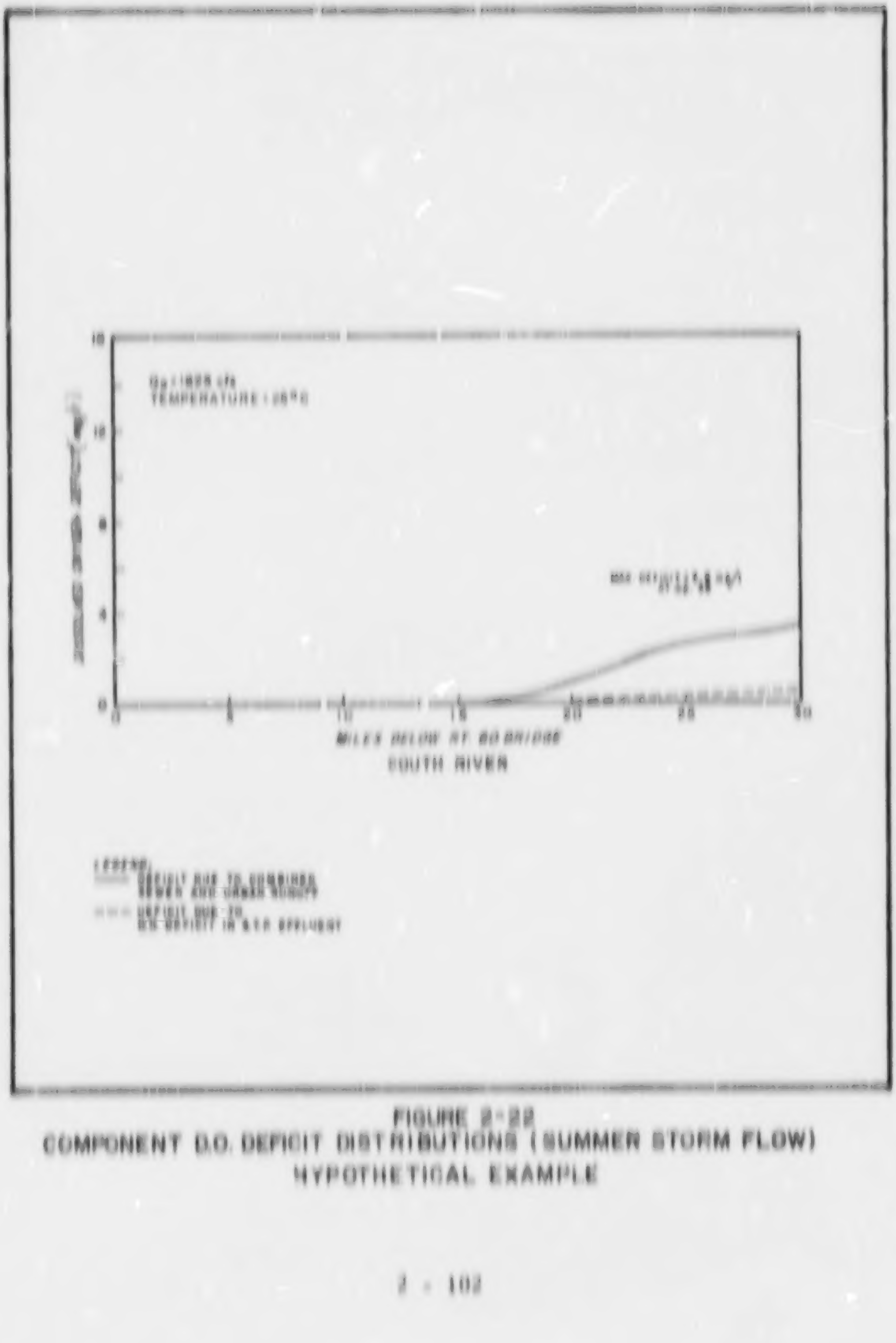


FIGURE 2-22
COMPONENT D.O. DEFICIT DISTRIBUTIONS (SUMMER STORM FLOW)
HYPOTHETICAL EXAMPLE

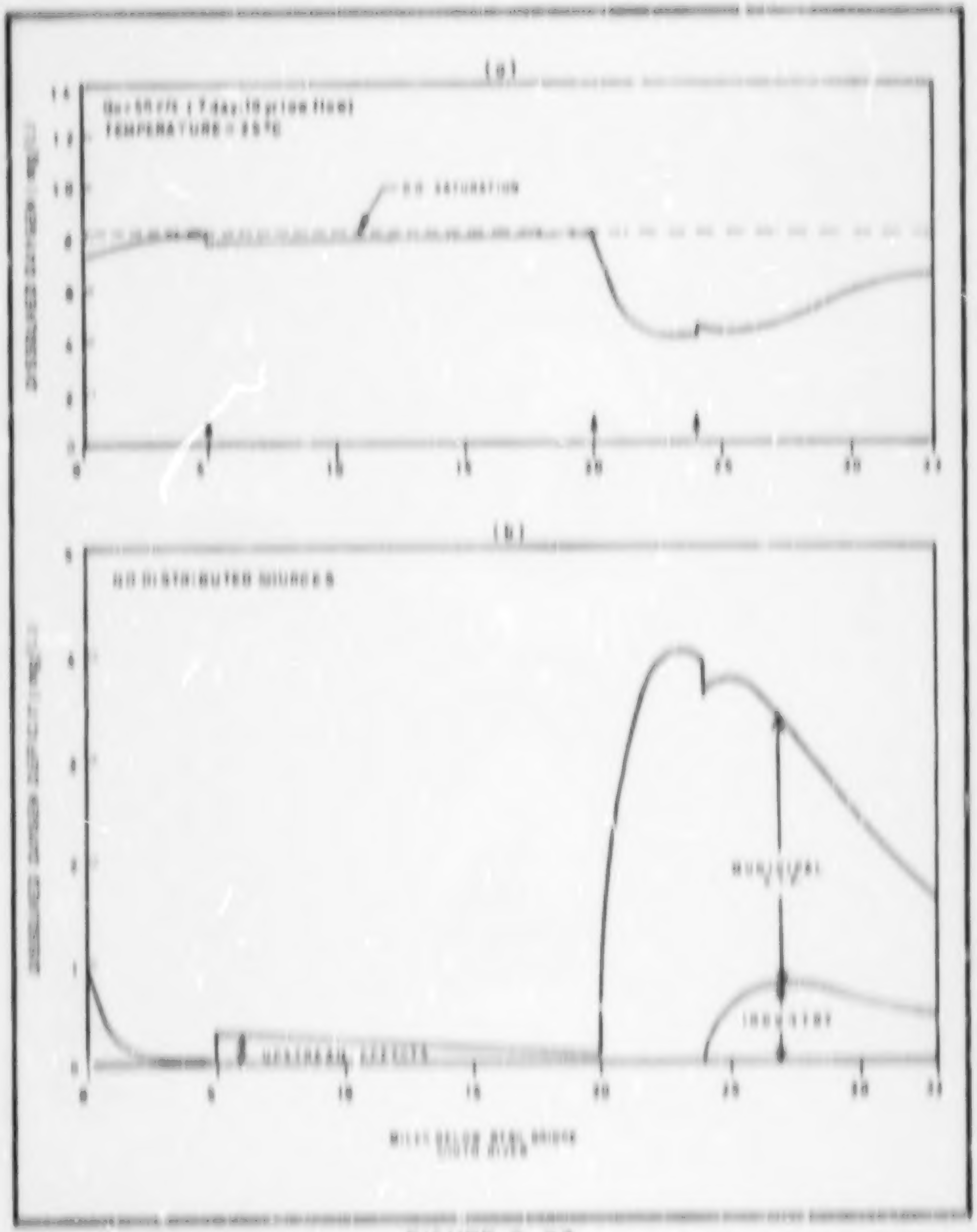


FIGURE 2-23
COMPUTED OXYGEN (DROUGHT FLOW) AND
COMPONENT D.O. DEFICIT DISTRIBUTIONS
HYPOTHETICAL EXAMPLE

discharge from the municipal Jefferson City STP is responsible for all of the deficit at the point of maximum deficit.

Therefore, based on a preliminary analysis, there is a probable dissolved oxygen violation in the South River at the 7-day, 1-in-10-year low flow.

Because of the probable problem, it is necessary to refine the analysis to increase the confidence level. Recommended areas of refinement are definition of the BOD reaction rate, the NBOD reaction rate, the river geometry at low flow, the benthic oxygen demand and any photosynthetic oxygen production or utilization. These refinements are discussed in Chapter 5.

2.7.2 Public Health

In a preliminary impact analysis, total coliform bacteria are considered as an indicator of the potential for health problems which arise from direct contact with the water. Since direct human contact with water usually occurs during the summer months, an annual average impact analysis is improper in most areas and only summer average or storm event analyses are performed.

For the interpretation of the results of a preliminary coliform analysis Table 2-23 can be used for guidance. In addition, a recent study by Johns Hopkins University (41), which relates total coliform bacteria to water-borne disease causing organisms, may aid in the interpretation of results.

TABLE 2-23
TOTAL COLIFORM ANALYSIS

If the Calculated Concentration Is:	Probability of a Coliform Problem
less than 100/100 ml	Improbable
less than 1000/100 ml	Possible
more than 1000/100 ml	Probable
more than 10,000/100 ml	Highly Probable

2.7.2.1 Summer Average Flows

The hypothetical South River coliform loading data has been presented in Table 2-15. In the impact analysis, the coliform decay rate is 1.0/day at 20^{0}C. Treating the coliform bacteria decay as a first order reactive substance, using a summer average flow of 250 cfs, and the average annual loads; the profile shown in Figure 2-24(a) is computed. As shown in this figure, the computed profile greatly exceeds the total coliform levels indicative of a highly probable problem. The combined sewer overflows are indicated to exert the predominant influence on the instream coliform concentrations. The other sources of pollution are calculated to contribute less than 700/100 ml of coliform bacteria. The conclusion to be drawn from this preliminary impact analysis is that any future efforts with respect to public health problems in the hypothetical 208 study should be directed to further quantification of the combined sewer overflow coliform loads.

2.7.2.2 Summer Storm Flow

An estimate of the instream coliform concentrations during a typical summer storm is presented in Figure 2-24(b) for the hypothetical example. A typical summer storm for the South River study area is characterized by an increase in stream flow to 3.2 times the annual average flow which results from 2 to 5 day steady rainfall of 7 times the annual average rainfall. As described in Section 2.5.3 the sewer overflow loading rates increase to 7 times the annual average loading rates during this storm period.

The instream coliform concentrations resulting from the combined sewer overflows during the storm is the major source of coliform pollution as is shown in this Figure. The preliminary analysis calculates instream coliform levels to reach a maximum of 280,000/100 ml. This concentration and the concentration for the entire river downstream of the city further substantiates the highly probable existence of a problem.

The direction to be followed for further coliform analysis should provide more information on the quantity and quality of the combined sewer

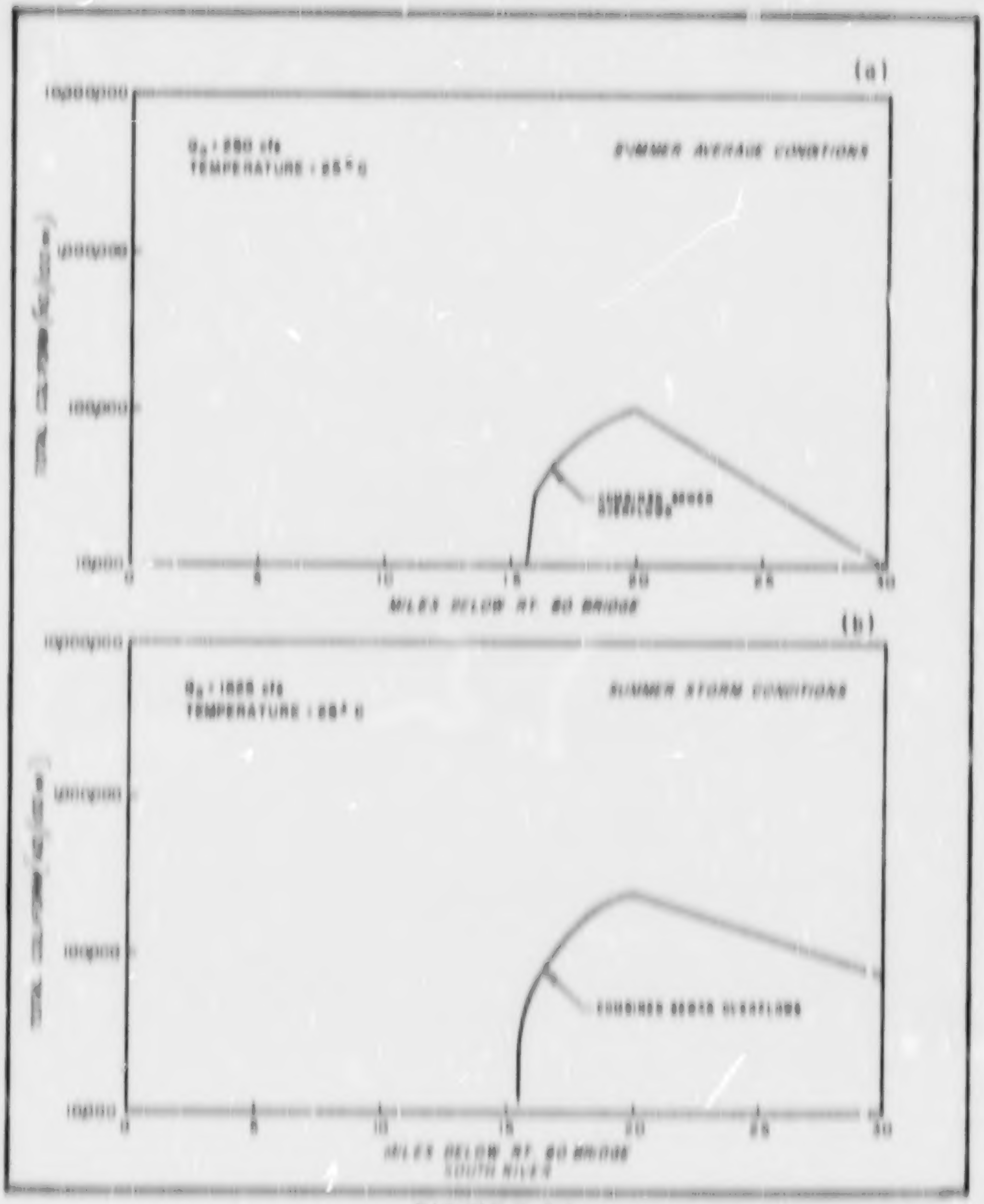


FIGURE 2-24
TOTAL COLIFORM DISTRIBUTIONS
(SUMMER AVERAGE FLOWS, SUMMER STORM FLOWS)
HYPOTHETICAL SOUTH RIVER EXAMPLE

overflow. This would require that instream coliform data and combined sewer overflow data be collected during both average conditions and during a long duration summer storm.

2.7.3 Eutrophication

The preliminary analysis of eutrophication is based on the following reasoning. If excessive quantities of both nitrogen and phosphorus exist, it is likely that, given the proper environment, algae will grow. Since the precise determination of these conditions is beyond the scope of a preliminary analysis, it is assumed that, in the absence of any contradictory data, conditions will be favorable for growth. Therefore, if the concentrations of both nutrients are in excess of growth requirements, a potential eutrophication problem exists. The interpretation of the calculated concentration of total nitrogen (TN), and total phosphorus (TP) nutrients in the receiving water is shown in Table 2-24.

TABLE 2-24
EUTROPHICATION ANALYSIS

If the Calculated Concentration is:	Probability of a Problem
TN less than 0.01 mg/l or TP less than 0.001 mg/l	Improbable
TN more than 0.1 mg/l and TP more than 0.01 mg/l	Potential
TN more than 1.0 and TP more than 0.10 mg/l	Probable

It is recognized that these concentrations are quite low and there are situations for which these concentrations are exceeded and no substantial biomass develops. Environmental factors, such as climate, geomorphology of the receiving water, turbidity, etc., are as important in determining whether a problem will develop as are the concentrations of available nutrients. Thus, these factors must be considered in modifying the conclusions drawn from the preliminary analysis.

The impact analysis for total nitrogen and total phosphorus is performed for an annual average and summer flow. For the summer or warm weather periods when plant growth is occurring, there is uptake of the nutrients by rooted plants or an uptake by planktonic forms which results in removal of the total nutrients by the algal synthesis and subsequent settling. In addition, phosphorus can be adsorbed to particles which settle. Thus, a removal rate is specified for the summer average condition. On an average annual basis, the nutrients that settled out during the summer can be returned to the flow during the scouring that occurs at high flows. If this occurs the annual average behavior is that of a conservative substance.

2.7.3.1 Annual Average Flow

The methodology presented in Section 2.6.3 is used to calculate preliminary nutrient concentrations in the sample drainage basin. The average annual stream flow of 500 cfs provides dilution of the total nitrogen and total phosphorus loads which are presented in Table 2-15. The calculated total nitrogen profile is presented in Figure 2-25(a). The total nitrogen concentration downstream of Milepoint 20 is 1.3 mg/l. It should also be noted that on a preliminary basis the municipal wastewater treatment plant and agricultural runoff are responsible for the majority of the nitrogen discharged to the South River.

Figure 2-25(b) presents the calculated total phosphorus profile. The municipal wastewater discharge provides about 70% of the instream phosphorus.

2.7.3.2 Summer Average Flow

Total nutrients are estimated by assuming nutrient removal is occurring during the algal growth period. For a preliminary analysis, total nutrients are removed at a rate of 0.1/day. When the dilution (upstream) flow is reduced to 250 cfs, and the point and NPS loading rates remain the same, the profiles presented in Figure 2-26 are computed. In general, the

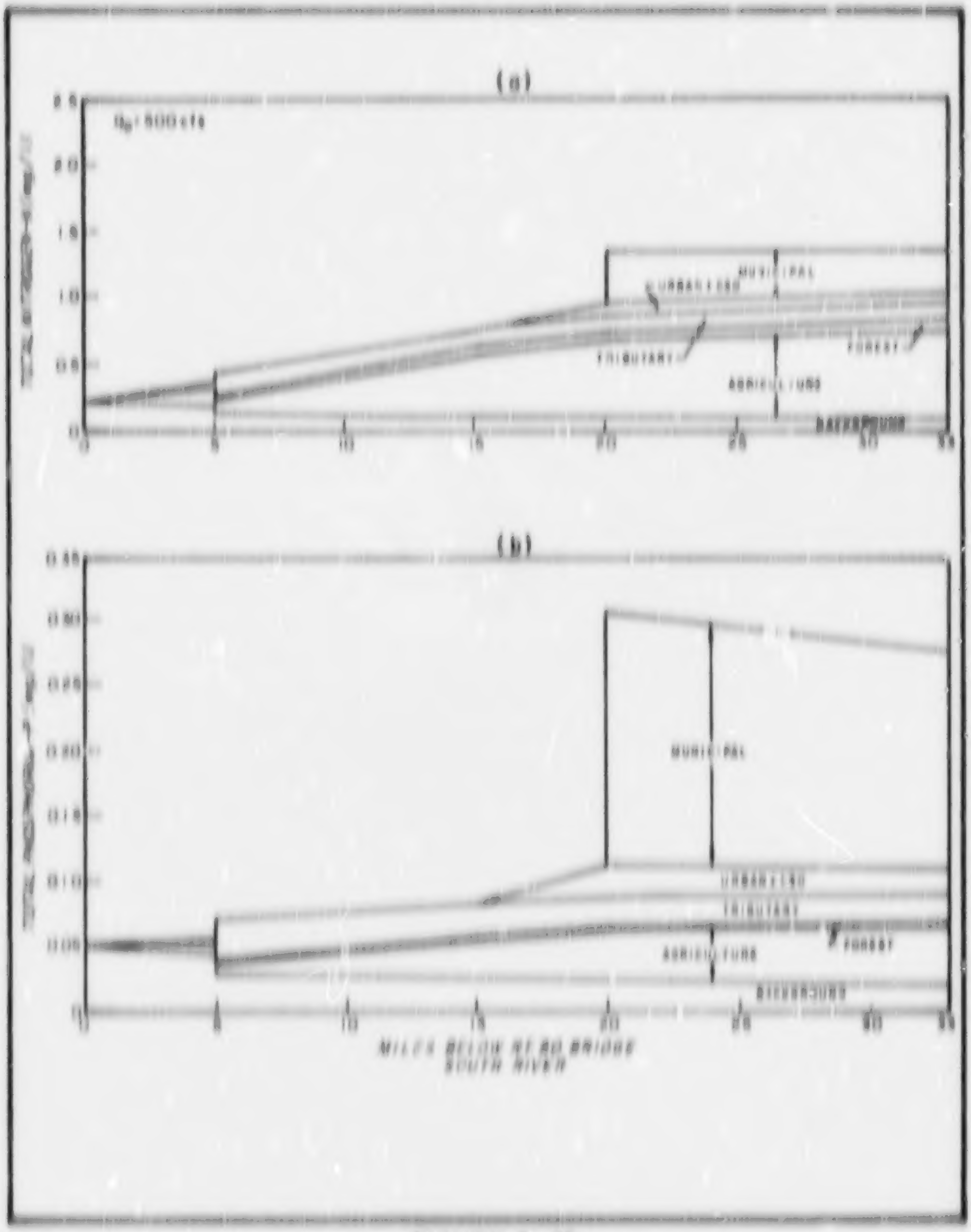


FIGURE 2-25
TOTAL NUTRIENT DISTRIBUTIONS
(ANNUAL AVERAGE FLOW)
HYPOTHETICAL EXAMPLE

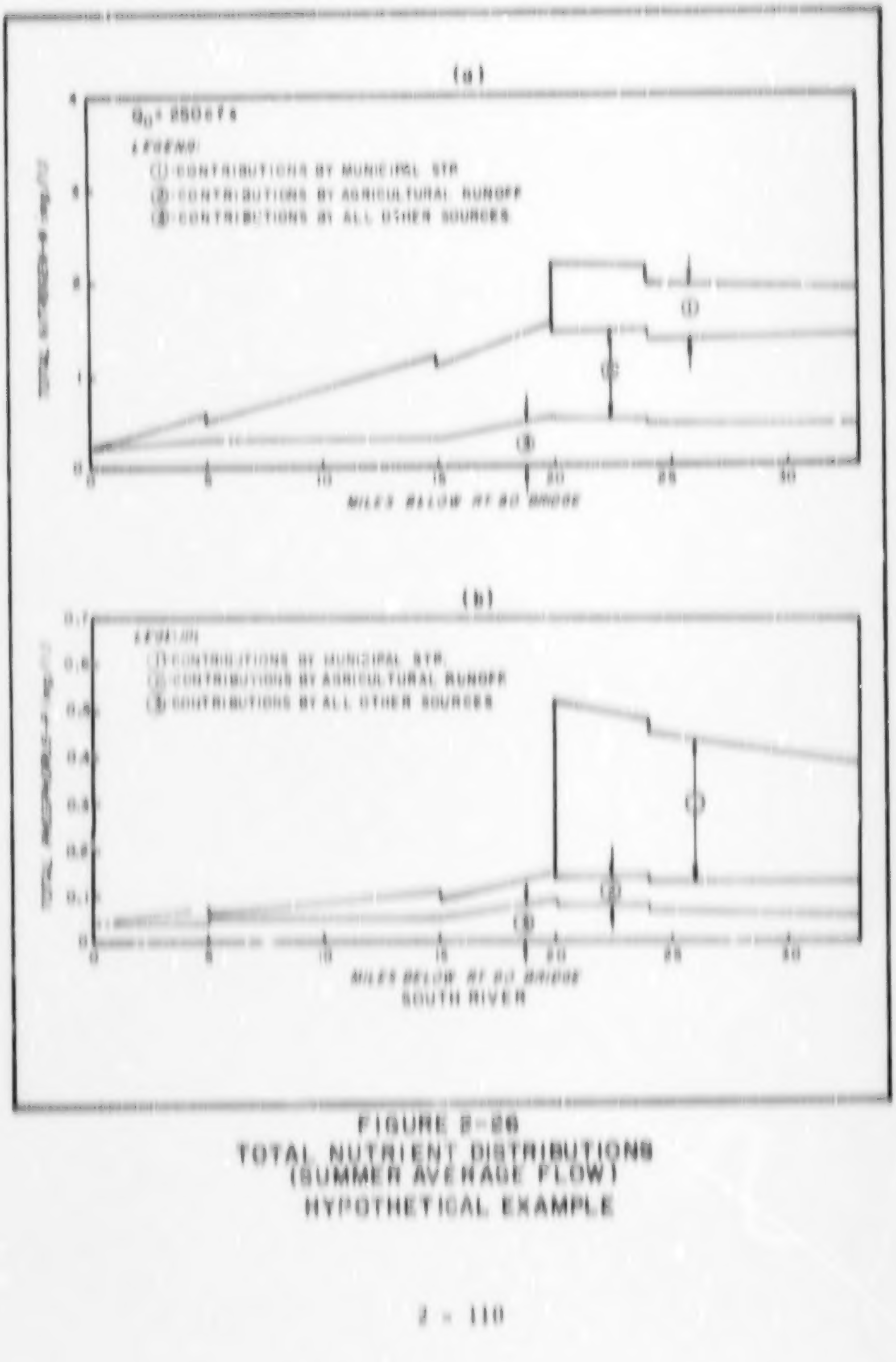


FIGURE 2-26
TOTAL NUTRIENT DISTRIBUTIONS
(SUMMER AVERAGE FLOW)
HYPOTHETICAL EXAMPLE

stream concentrations of total nutrients approximately double. Also, as shown for the annual average flow, the agricultural NPS nitrogen and municipal nitrogen loads are responsible for the majority of the calculated instream nitrogen. The municipal wastewater treatment plant effluent contributes by far the majority of the phosphorus to the South River.

Based on a preliminary analysis, the potential for a eutrophication problem is indicated for the South River. Nutrient concentrations are greatly in excess of that required for substantial algal biomass. However, two factors may mitigate against its development. The travel time through the stream is ten days or less (Figure 2-9) and relatively high suspended solids concentration are calculated in Section 2.7.4, which would limit light penetration. Hence, it is clear that further analysis is necessary before a definitive assessment can be made.

2.7.4 Other Water Quality Interferences

The other water quality interferences can be caused by substances that are either conservative, reactive or sequentially reactive. For example purposes, total suspended solids are evaluated for the hypothetical South River 208 study. For an approximate analysis, the total suspended solids are considered to be conservative.

The interpretation of total suspended solids concentrations, TSS, are tentatively based on the levels indicated in Table 2-25.

TABLE 2-25
TOTAL SUSPENDED SOLIDS

If Calculated Concentration is:	Probability of a Problem
Less than 10 mg/l	Improbable
Less than 100 mg/l	Potential
More than 100 mg/l	Probable

2.7.4.1 Annual Average Flow

The estimated TSS NPS loads and known point source loads previously discussed are used as the input data for the impact analysis. The calculated instream TSS concentrations are shown in Figure 2-27(a) using the annual average stream flow for dilution of the loads. The computed unit responses for each land use show the agricultural NPS TSS loads account for over 90% of the instream suspended solids.

2.7.4.2 Summer Storm Flow

As discussed in Section 2.5.3, a summer storm in the sample South River Basin has been defined as having 7 times the average annual rainfall intensity over a 2 to 5 day period. This increased rainfall results in an increase in the stream flow to 3.2 times the average flow. During this type of storm, the impact of urban sources are evaluated. The calculated total suspended solids profile for these conditions is presented in Figure 2-27(b).

Total suspended solids increase over existing conditions is 50 mg/l. Therefore, the urban point and intermittent point sources create a potential total suspended solids problem in the South River during a long duration summer storm. Hence, a more detailed analysis is required together with a data gathering program.

2.7.5 Summary of Results of the Impact Analysis

The preliminary assessment of the hypothetical South River planning area indicates that problems in all the categories analyzed are either probable or highly probable. However, the causes of these problems have been restricted to only certain of the sources of mass within the drainage area. Table 2-26 presents the results in a compact form. It is clear from this compilation that agriculture, and point sources are each important in assessing dissolved oxygen and eutrophication problems. Further, coliforms are dominated by urban combined sewers while suspended solids are dominated by agriculture and urban combined sewers.

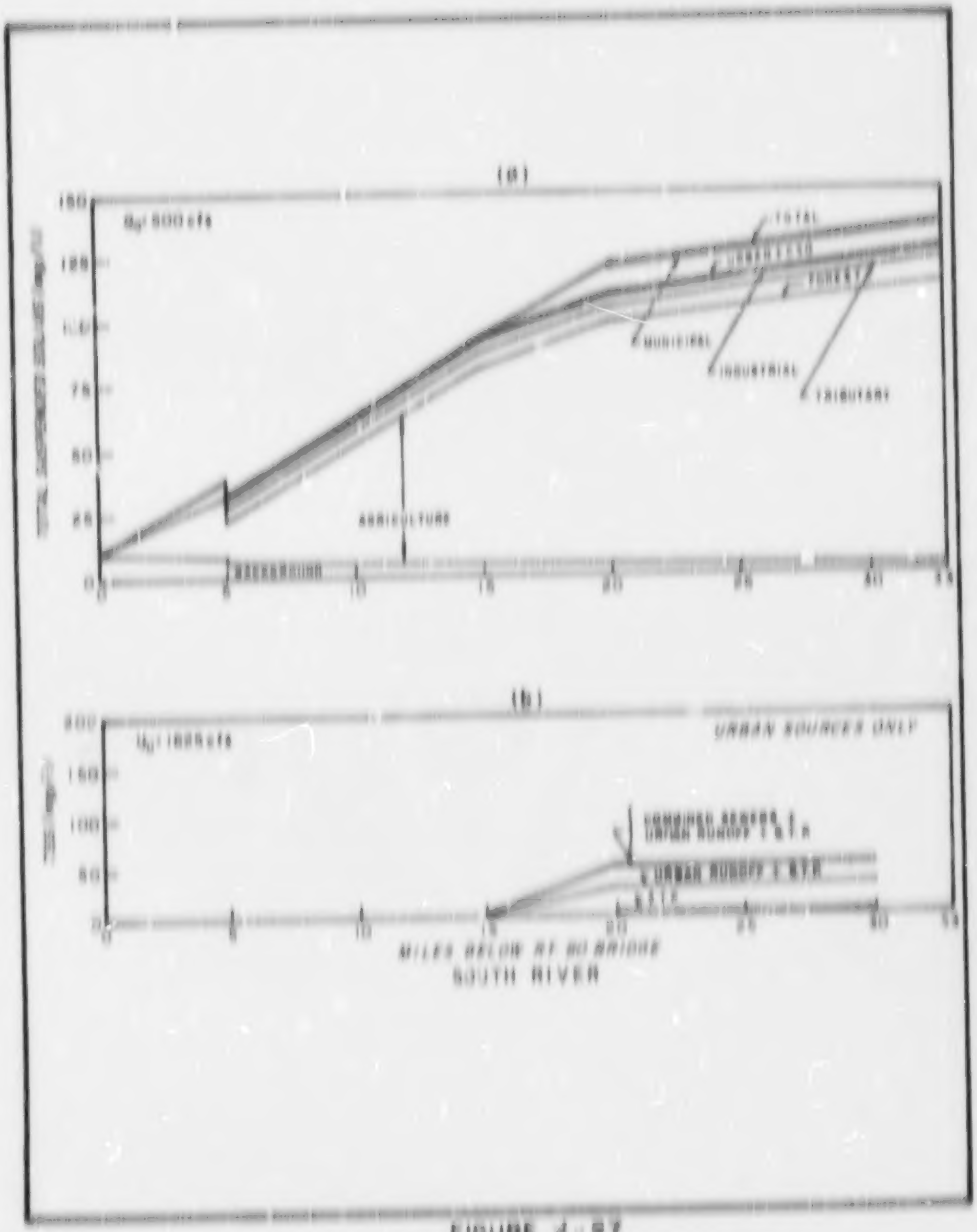


FIGURE 2-57
TOTAL SUSPENDED SOLIDS DISTRIBUTIONS
(ANNUAL AVERAGE FLOW, SUMMER STORM FLOW)
HYPOTHETICAL EXAMPLE

TABLE 2-[illegible]

SIGNIFICANT SOURCES OF [illegible] [illegible] [illegible] WATER QUALITY PROBLEMS
([illegible] [illegible])

Sources	Dissolved Oxygen	Public Health	Eutrophication	Suspended Solids
Agriculture	Significant contributor to probable problem at summer flow.	—	Significant contributor to [illegible] problem at annual and summer flow.	Predominant contributor to potential problem at annual and summer flow.
Forest	Not likely to be a significant contributor to any of the listed problems			
[illegible] [illegible]	—	—	Further analysis required	—
[illegible]	—	—	Further analysis required	—
Urban NPS	Not likely to be a significant contributor to any of the listed problems			
Urban combined sewers	Significant contributor to a likely problem at summer flow and predominant contributor at storm flow.	Predominant contributor to a highly probable problem at summer and storm flow.	Further analysis required	Predominant contributor to probable problem at storm flow.
Point Sources	Significant contributor to probable problem at summer flow and predominate or exclusive at drought flow.	—	Significant contributor to probable problem at annual and summer flow.	—

Two sources, the runoff from the forested areas and urban runoff from non-sewered areas, can be eliminated from further considerations.

In summary, the preliminary impact analysis methodology and the load estimate generation procedure presented previously is given as a suggested procedure. It is realized that there are and will be some areas of the technique which are subject to question. However, the procedure presented can, in many cases, put a proper perspective on the problem. The preliminary analysis might identify specific areas for additional analysis or it might identify areas which warrant additional data collection. In some instances the analysis will account for the total extent of the mathematical modeling analysis which is needed for the 208 project.

If pollution sources, such as combined sewer overflows, are identified as being responsible for affecting water quality then further analysis might be in order. Chapter 3 and Chapter 4 can aid the analyst in a proper direction to take for the additional analysis. If the water body is more complicated than a stream, then both the preliminary data collection and the load generation should help the analyst put a better perspective on the sources of pollution. In addition, Chapter 5 will help by introducing higher level modeling techniques which are available for water quality impact analyses.

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CHAPTER 3

PROCEDURES FOR ASSESSMENT OF URBAN POLLUTANT SOURCES AND LOADINGS

3.1 Introduction

This chapter discusses procedures for the assessment of waste loads generated in urban areas at a higher level of refinement and detail than employed in the preliminary analysis described in Chapter 2. Since the assessment methodology for continuous point sources, at the higher level of refinement, is very similar to procedures presented in Chapter 2, Chapter 3 emphasizes procedures for those urban loads which enter receiving waters as intermittent point sources, and provides a limited discussion of the applicability of these procedures for estimating the impact of non-point source urban loads. A more complete discussion of the assessment methodologies for non-point source non-urban loads is presented in detail in Chapter 4.

3.2 Identification of Level of Sophistication Required

The output from a preliminary assessment as discussed in Chapter 2, is a broad identification of major pollutant sources within an urban area along with a perspective on the relative magnitude of the pollutant loads generated, the temporal and spatial distribution of these loads, and a preliminary assessment of the impact of these loads on water quality problems within the planning area.

Once the major pollutant loads have been identified and can be attributed to sources for which control measures are possible, assessment procedures with higher levels of sophistication should be employed to refine the previous loading and impact estimates. At higher levels of refinement, it is appropriate to consider the changes in the temporal and spatial distribution and magnitude of loads from sewered and non-sewered urban areas. This allows the planners to further differentiate mass pollutant loadings as modified by the nature and extent of storm and combined sewer conveyance, retention and treatment facilities.

Although predictive methodologies and analytical approaches with a high level of sophistication and detail are described in Appendix A of this manual, the procedures recommended for the level of assessment in this chapter are the simplest of the available techniques that will allow estimation of pollutant loadings and impacts necessary to support the decisions that must be made. While it is generally accepted that higher levels of sophistication will permit more accurate or reliable pollutant load quantification and impact analyses, the decision to use highly sophisticated procedures for problem assessment must be tempered with an understanding of the inherent weaknesses and limitations of the overall analysis. These limitations stem from measurement errors in rainfall related pollutant loadings, from the complex nature of pollutant transport mechanisms within urban drainage areas and from the wide range of physical and chemical transformations that occur in the receiving waters.

Another point that must be considered in this second level of refinement in the analysis is the choice between very precise and accurate estimates of the loads from a small number of events or a less refined analysis of longer term loading histories. This choice often depends on such factors as the availability of historical rainfall and stream flow data, the physical characteristics of the drainage area and the water quality standards of the receiving water.

The justification for detailed analysis at higher levels of sophistication is related to the environmental and economic risks involved in decisions made from analyses with lower levels of precision and refinement. These risks should be balanced against the cost for data collection and analysis associated with the sophisticated procedures. Balanced analytical frameworks and data collection activities should be developed for the major loading components and associated receiving water responses.

3.2.1 Identification of Appropriate Time Scale

Pollutant loadings from urban areas may be separated into two categories: those which are related to storm events and those which are not. Storm events are highly variable in magnitude and transient in nature, occurring randomly in time. Combined and separate storm sewer overflows and surface runoff through natural channels are generated by storm events, and therefore have similar characteristics, though different in magnitude. The component of rainfall which is lost to soil infiltration may also generate loads, via the transport or leaching of soluble pollutants. The characteristics of loads entering a stream from groundwater are quite different from the loads associated with surface runoff. All or part of these percolating loads may remain as groundwater, or infiltrate sewer lines. That portion which does enter the receiving water could tend to do so over an extended period of time and over an extended area. Thus, storm events can generate highly-variable transient loads which are discharged directly to the receiving water as well as diffuse indirect loads which enter the receiving water through groundwater inflow attenuated beyond the actual rain event.

Urban loadings not associated with storm events include the typical point source discharges from municipal and industrial treatment plants, continuous discharges of raw sewage from faulty regulators, inadequate or partially filled interceptors, treatment plant bypasses, and groundwater inflow pollutant loadings from sources such as improperly functioning septic tank leach fields and improperly designed or operated landfills. Such loadings are more or less continuous, except for the diurnal activity of municipal and industrial sources and seasonal activities from specific industries. Urban pollutant loadings, therefore, are time dependent to varying degrees.

Waste loads with a low order of time dependence may be characterized on a yearly basis (pounds/year), and prorated linearly down to some time interval of interest (pounds/month, pounds/day). Except for cases where significant seasonal changes occur, such as population movement in vacation areas or seasonal industrial activity, such prorated daily or monthly loading rates will be fairly representative of the actual loading rates from the source during these periods.

For transient storm generated loads, this is not the case. A yearly stormwater loading rate represents the sum of all individual storm loads which have occurred throughout the year. If such annual loads are prorated down to monthly or daily loading rates, the resulting loads are artificial, since the distribution of rainfall is not uniform. In the characterization of storm loads, an average annual loading rate may be used as a measure of the relative impact of storm runoff. For example in a case where sediment deposits in the receiving water are a primary concern, the cumulative effect of all storm overflows is more significant than that of an individual event or a specific period within an event. For this case, it is unimportant whether a prorated daily or monthly loading rate reflects the instantaneous rate during that period, as long as the cumulative load calculated by using these rates is representative of the long term loading to the receiving water. Long term loading characterizations are appropriate where the impacts of storm overflows are not confined to occurrences during individual storm events. Impacts may be observed at any time, and possibly become most severe only during non-storm periods.

Where water quality impacts from stormwater overflows are as transient as the occurrence of the overflows, the long term average loading becomes much less important, and represents only the first step in the characterization of storm runoff. Coliform organisms, which are present in storm overflows and have relatively rapid die-off rates in natural waters, may be used to illustrate this point. If a coliform load enters a receiving water during a 6-hour storm event, the peak concentration observed in the receiving water would generally be restricted to that order of time. Based on the magnitude of the load, the transport characteristics of the drainage area and receiving water, and the die-off rate of the coliforms, the total impact will often be dissipated before the next storm occurs. In this case, yearly or monthly average loading rates do not adequately indicate the actual load during a storm. Further, they do not provide information on whether the resulting receiving water concentrations are objectionable, or how often concentrations in excess of stream standards or water quality objectives may be observed. These average loads for pollutants with short-term transient impacts can be useful for identifying the significance of a particular source or the magnitude of a problem. Reliable assessment, however, requires a greater level of detail in the definition of such loads.

Figure 3-1 illustrates various levels of refinement which might be employed in the definition of transient stormwater loads. It represents the transition from a relatively simple average yearly loading to a quite detailed representation of storm runoff accomplished by introducing additional temporal detail. The level of refinement proceeds as follows:

Level 1. Average yearly storm load
Level 2. Actual event distribution
Level 3. Variation within events

Level 1 uses the average annual stormwater loading rate, W_0, as was used in Chapter 2. W_0 is calculated by determining the total storm load during the year (pounds), and assuming that it occurs continuously (during both rain and non-rain periods). Confidence in the value of W_0 would require the monitoring of all storm loads over a period of several years. This is impractical within the 208 planning and assessment time frame. Most storm analysis techniques must rely, at least initially, on estimates of such values extrapolated from other studies or projected from data secured from limited areas and limited time periods.

Level 2 considers the actual temporal distribution of stormwater events. It indicates the variability of the pollutant load from event to event. It does not, however, indicate how the load varies within each event. The variation of runoff load per event is due primarily to the amount of rainfall occurring during each event. It is also due to the variation in time between storms which affect surface debris inventory, and to seasonal changes in debris accumulation in the drainage basin (e.g., leaf fall, spring fertilization, etc.).

Level 3 describes the actual runoff loading rate for all storm and for any time within each storm, whether it be hour by hour or minute by minute

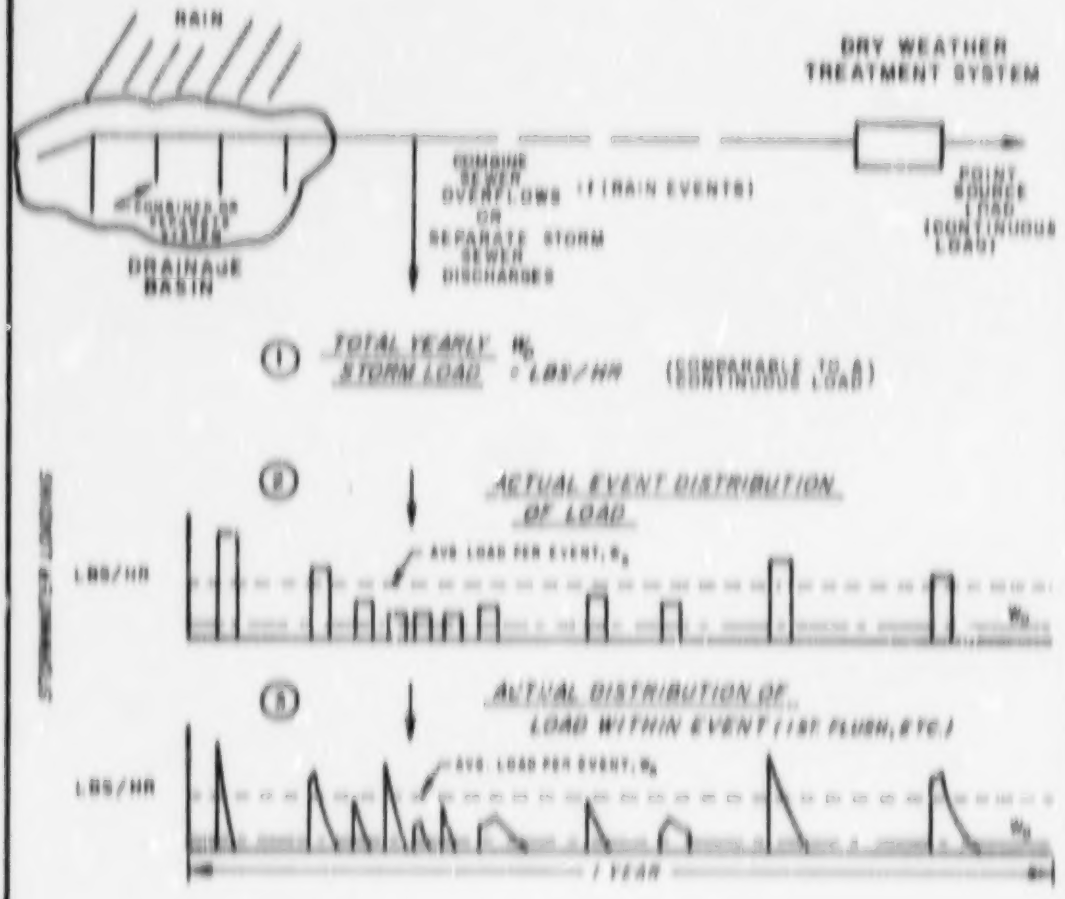

RAIN
DRY WEATHER TREATMENT SYSTEM
COMBINED OR SEPARATE SYSTEM
DRAINAGE BASIN
COMBINED SEWER OVERFLOWS OR SEPARATE STORM SEWER DISCHARGES
(RAIN EVENTS)
POINT SOURCE LOAD (CONTINUOUS LOAD)
① TOTAL YEARLY STORM LOAD = W_0 LBS/HR (COMPARABLE TO A CONTINUOUS LOAD)
STORMWATER LOADING
② ACTUAL EVENT DISTRIBUTION OF LOAD
LBS/HR
AVG LOAD PER EVENT, W_E
W_0
③ ACTUAL DISTRIBUTION OF LOAD WITHIN EVENT (1ST FLUSH, ETC.)
LBS/HR
AVG. LOAD PER EVENT, W_E
W_0
1 YEAR

FIGURE 3-1
VARIOUS LEVELS OF DETAIL IN
STORMWATER LOAD CHARACTERIZATION

characterization. This level indicates the "first flush" effects, varying storm patterns, and varying intensity within the storms.

When it becomes inappropriate to use the long term average pollutant loading rate, W_D, in an impact analysis, then some higher level of stormwater loading definition must be provided. Selection of an appropriate level of detail in definition of storm loads is best dictated in assessment studies by receiving water impacts. Pollutants discharged to receiving waters have characteristic time and space scales associated with the impacts they cause. These scales are illustrated by Figures 3-2 and 3-3, and can be used to provide guidance in determining the time scale of the averaging which is appropriate.

Thus, while suspended solids loads may, in most cases, be characterized on an annual basis, more reactive contaminants (coliform organisms, oxygen consuming materials) will usually require definition on a scale in the range of hours. Note that waste load definition on a scale finer in detail than one to several hours (approximately the scale of storm events) is not necessary for the evaluation of transient water quality impacts. Assessment studies will, therefore, not normally require load definition in greater detail than that represented by Level 2 in Figure 3-1.

Urban areas generate both continuous and intermittent point source wastewater loadings. The continuous point source loads will now be discussed. The intermittent point source loads are discussed in Section 3.4.

3.3 Characterization of Continuous Urban Point Source Loads

The methodology for characterizing continuous point source loads described in Chapter 2 remains appropriate at the higher levels of refinement discussed in this chapter. The data should be sufficient to allow for a reliable estimate of continuous point source loads. These loads are the most obvious in an urban area, they are usually important, and information will usually be available for adequate characterization.

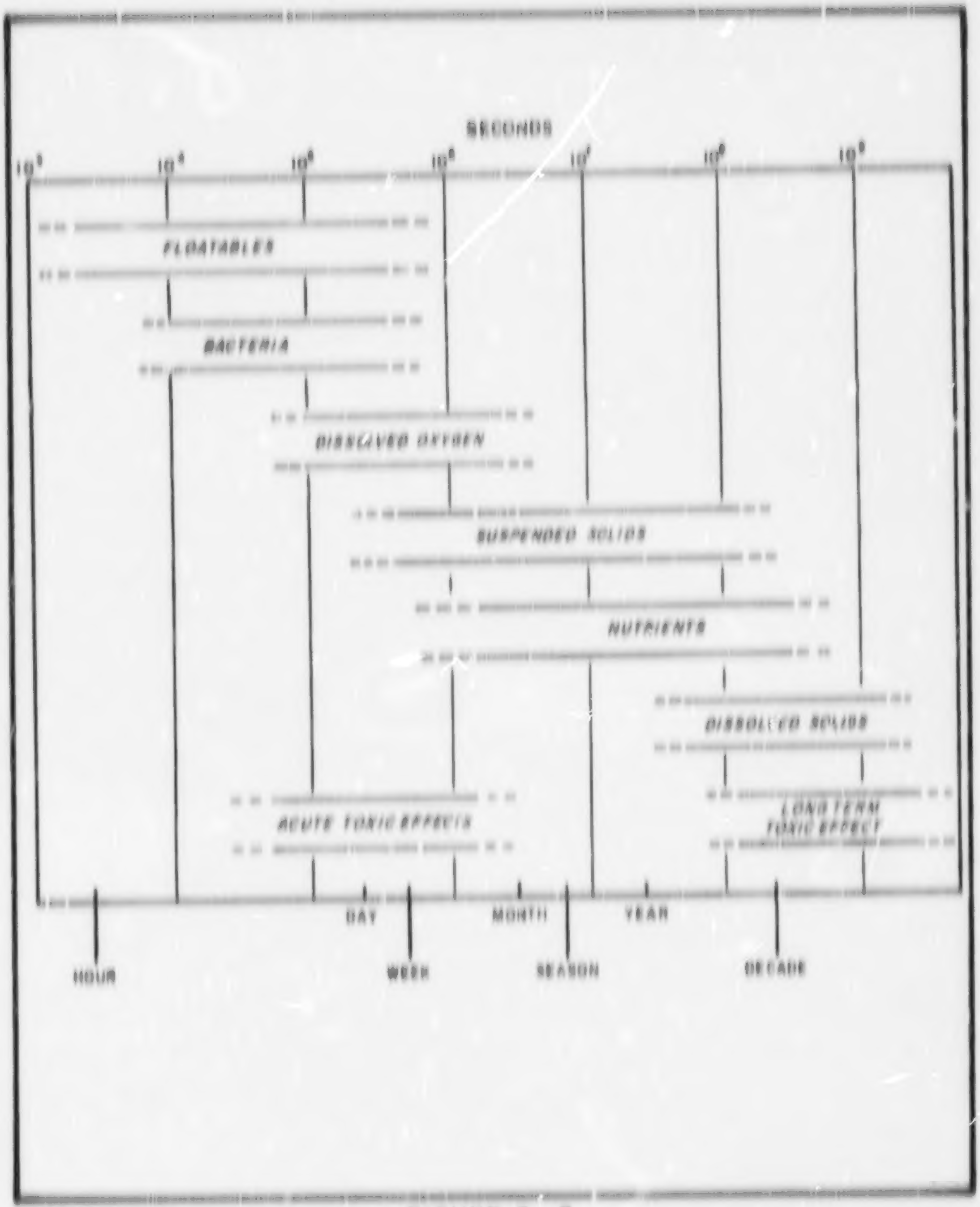


FIGURE 3-2
TIME SCALES
STORM RUNOFF WATER QUALITY PROBLEMS

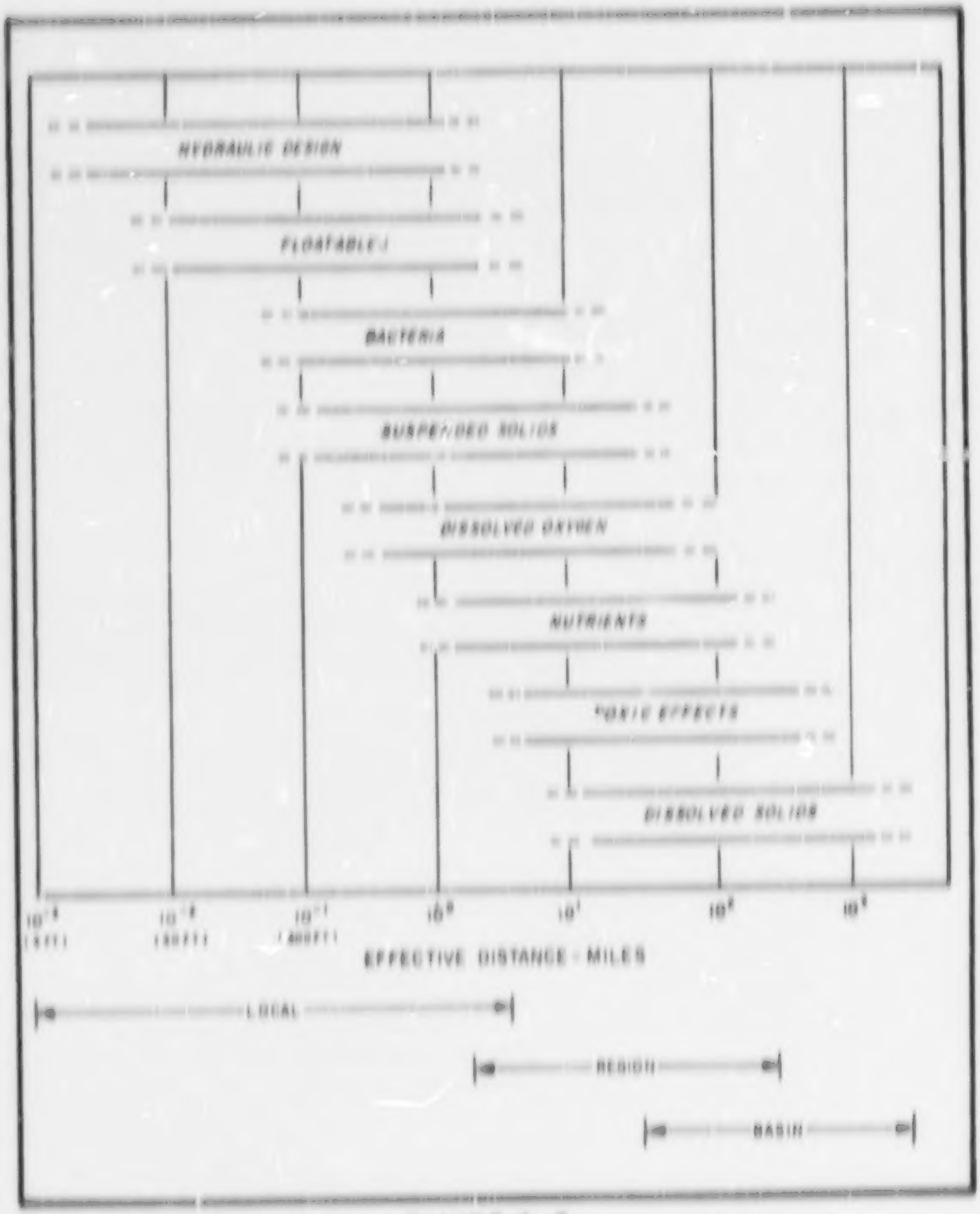


FIGURE 3-3
SPACE SCALES
STORM RUNOFF WATER QUALITY PROBLEMS

The assessment of waste loads from an urban area seeks to identify the relative significance of loads from different sources. Since many of the urban loads (intermittent point sources, non-point loads) will require characterization by estimating techniques, the overall assessment will be strengthened by accurately characterizing those loads for which an adequate data base exists. Municipal and industrial point source discharges usually fall into this category.

3.3.1 Municipal Continuous Point Loads

As described in Chapter 2, waste loads from municipal treatment facilities should be well quantified and documented. Sources of such data accessible to the 208 Agency include treatment plant records, state or local regulatory agency records, EPA NPDES (National Pollution Discharge Elimination System) permit data or monitoring reports. An additional source of data on municipal and other point source loads may be found in study reports for 201 Facilities Plans and for 303-(e) Basin Plans, where these have been completed in the area. The Regional EPA offices maintain lists of completed basin plans for their region. These plans will normally contain, in addition to data on point source loads, information on water quality standards and objectives and on allocations of waste loads from point sources.

There is a class of municipal continuous waste loads which will not normally be documented or easily identified, but which may be significant sources of load in some areas. Many cities with combined sewer systems discharge unmonitored waste loads continuously as a result of defective or improperly operated regulators and bypasses, partially filled interceptors, or interceptors whose capacity is exceeded by normal dry weather flows during some period of the day. Dry weather overflow data for these discharges will not normally be available but it may be possible to estimate them. Public works or sewer maintenance departments or regulator and interceptor maintenance crews are sources of information. Urban areas with separate sewer systems may also have significant discharges from the sanitary sewer systems. During periods when the groundwater tables are high, significant groundwater infiltration often occurs and excess flow from the sanitary sewers may be bypassed at the plant or at upstream locations, thereby producing an often overlooked pollutant load to the receiving stream. In addition, separate sewered areas may have continuous discharges from storm sewers caused by unauthorized connections.

3.3.2 Industrial Continuous Point Loads

With the enactment of the Water Pollution Control Act Amendments of 1972 (PL 92-500) the NPDES program was established (1). With this program, the Federal Government established long term goals for industry to achieve increased abatement of pollutants discharged to the nation's waterways. As discussed in Chapter 2, all industries are required by law to obtain a discharge permit, and to continually report to the state and/or federal agency the quality of the discharge to the receiving water. The permit indicates the effluent limit for discharges to the receiving water. The compliance monitoring programs mandated by NPDES report regularly on the actual discharges.

As with the municipal point source loads, there should be a sufficient amount of data available to allow for a determination of existing industrial loadings. Discharge permit requirements or results of monitoring programs can be obtained from the EPA Regional Office, the state regulatory agency, or possibly from the specific industrial dischargers. Most of the present effluent limits are interim in nature, and the Federal Government has set a specific time table during which certain effluent requirements must be met. Current regulations require that all industries achieve Best Practicable Treatment (BPT) by 1977 and Best Available Treatment (BAT) by 1983. To provide the 208 planner with a basis for making estimates of these future industrial loadings, effluent concentrations for some typical industries are provided.

Each industry is assigned a code number by the Department of Commerce, depending on the specific products which it produces. The first two digits of the Standard Industrial Classification (SIC) Codes for a few sample industries are as follows:

SIC	Type Industry
20	Food and Kindered Products
22	Textile Mill Products
26	Paper and Allied Products
28	Chemical and Allied Products
29	Petroleum and Coal Products
33	Primary Metal Products

The effluent pollutant concentrations to be expected under the different levels of removal for each SIC Industry type for both BPT and BAT are presented in Tables 3-1 and 3-2, respectively. It must be emphasized that the mean effluent characteristics shown in these tables represent only approximately the average discharges for each industry. The actual pollutant discharges will vary widely from one sub-category to another within a given industry. There can be a number of different types of plants within a specific industry with differing manufacturing processes and products. An additional factor is the varying water usage per unit of production from plant to plant. Therefore, these estimates should not be taken as characteristic of an entire industry. They provide only a rough estimate of the mean effluent pollutant concentration. Additional guidance for estimating such effluent concentration can be obtained from the EPA Development Document for a specific industry which describes the basis on which the discharge limitations were established (2 thru 14).

It should be noted that all of the effluent guidelines are not finalized and that many industries are in negotiations with EPA concerning the validity of the current effluent limits. Therefore, the effluent concentrations in Tables 3-1 and 3-2 should only be used if no other information is available.

In instances where the receiving stream which receives the industrial discharge is classified as "water quality limited", the EPA must make effluent allocations for each industry on a case by case basis. Generally, such allocations will differ from the values discussed above, and will be written into the permit along with a compliance schedule for meeting the allocation.

TABLE 3-1

TYPICAL INDUSTRIAL EFFLUENT CONCENTRATIONS
BPT - "1977"
APPROXIMATE MEAN EFFLUENT CHARACTERISTICS[a]
(in mg/l)

Parameter	20 Food	22 Textiles	26 Paper	28 Chemicals	29 Petroleum	33 Metals
TSS	40[b]	49[b]	58[b]	40[b]	10[b]	20[b]
BOD_5	29[b]	22[b]	30[b]	30[b]	15[b]	38[b]
COD	135	225[b]	156	1400[b]	102[b]	-
TDS	-	700	3785	4350	-	-
Cl	565	25	135	-		-
Total-P	17	2	-	5		.50
Total-N	50	2	-	20	70	62[b]
Lead	-	.03	-	2[b]		.25[b]
Zinc	-	5	-	0.25[b]		.25[b]
Cadmium	-	.005	-	0.225[b]		.15[b]
Oil	10[b]	10	-	15[b]	5[b]	5[b]

[a] Represents an approximate estimate of the mean effluent concentrations for each industry. The pollutant concentration could vary widely within an industry as a result of varying water usages.

[b] Concentrations developed from effluent guidelines which exist for these parameters, other concentrations were obtained from any existing treatment plant data found in the Development Documents (2-14).

TABLE 3-2

TYPICAL INDUSTRIAL EFFLUENT CONCENTRATIONS
BAT - "1983"
APPROXIMATE MEAN EFFLUENT CHARACTERISTICS[a]
(in mg/l)

Parameter	20 Food	22 Textiles	26 Paper	28 Chemicals	29 Petroleum	33 Metals
TSS	10[b]	8[b]	23[b]	13[b]	5[b]	5[b]
BOD_5	7[b]	11[b]	22[b]	15[b]	5[b]	4[b]
COD	48	72[b]	88	460[b]	26[b]	-
TDS	-	700	3785	4350	-	-
Cl	565	25	135	-	-	-
Total-P	1.2	2	-	3	-	0
Total-N	9[b]	2	-	3	28	5[b]
Lead	-	.05	-	1[b]	-	0[b]
Zinc	-	5	-	.25[b]	-	0[b]
Cadmium	-	.005	-	.05[b]	-	0[b]
Oil	10[b]	10	-	5	1.35[b]	5[b]

[a] Represents an approximate estimate of the mean effluent concentrations for each industry. The pollutant concentration could vary widely within an industry as a result of varying water usages.

[b] Concentrations developed from effluent guidelines which exist for these parameters, other concentrations were obtained from any existing treatment plant data found in the Development Documents (2-14).

3.3.3 Need for Monitoring

Specific monitoring efforts for point source continuous discharges may be advisable or necessary during an assessment study. Although, as indicated earlier, it is likely that a fairly comprehensive data base on such loads is available, efforts to provide supplementary data by means of a monitoring program may be indicated for a number of reasons. Some of the more often encountered reasons are:

1. Need to verify data reported from municipal and industrial sources
2. Need to develop temporal and spatial data for complex situations where ongoing stream surveys are being performed.
3. Need to quantify impacts from previously unidentified sources, such as overflows caused by severe infiltration of separate sanitary collection systems, faulty regulator operations in combined sewer systems, partially filled interceptors, or unauthorized connections to storm sewers
4. Need to obtain specific contaminant information for cases where appropriate sources were monitored but contaminants of interest were not included.

3.4 Characterization of Intermittent Point Source Loads

Because of their variability, intermittent point source loads require the use of unique estimating procedures for adequate quantification. Extensive data on storm runoff loadings have been obtained in recent years and have been reported in the literature (15-19). These provide an immediate source of information, but are not a substitute for local data and analysis. Unless reported data have been collected in the study area, local data must be collected and used in developing estimates of storm loads. The need for adequate local data is based upon the following factors:

1. Differences in rainfall frequency, intensity, and duration along with drainage area characteristics significantly influence storm loads.

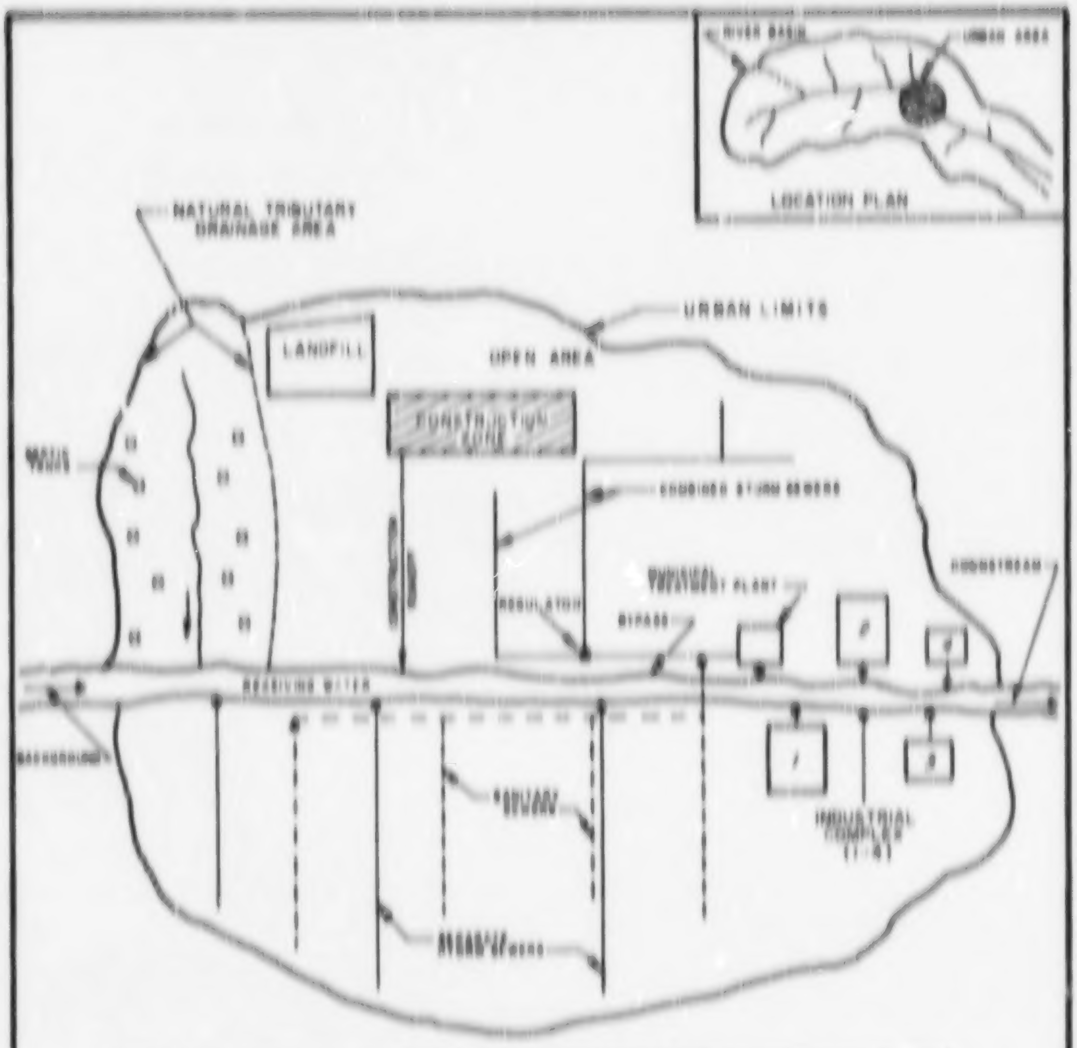
2. Significant variations in loads from individual storms are observed in the same area.
3. Studies which develop loading data generally cover relatively short periods of time compared with the long term patterns of rainfall in any area.

The most important factor in the generation of intermittent (storm) loads is rainfall. Rainfall data for an area should be among the first set of local data obtained and analyzed. All of the load estimating methods employ rainfall as the fundamental data input.

Hourly rainfall records for U.S. Weather Bureau stations in the study area may be obtained from the National Weather Records Center, Asheville, North Carolina, either on magnetic tape or on punched cards. For a long term period, the cost of such records is approximately $100 per gage.

In addition, data from local rain gages may be obtained from sources within the study area, reduced to an hourly record and utilized in a similar fashion. Data from the U.S. Weather Bureau stations should always be analyzed, because the data are reliable and will generally cover the longest historical record. Data from local gages are often an important source of more area-specific information and should be analyzed whenever available. The actual use of the data depends upon the methodology employed, and is described further in Sections 3.4.3 and 3.4.4.

Other data inputs required are the drainage basin and land use characteristics of the study area. For urban areas, this can be initally summarized (as illustrated in Figure 3-4) by the relative distribution of land use classifications (residential, industrial, commercial, open, etc.) served by basic conveyance systems (combined sewers, separate storm sewers, natural conveyances). Appendix C and the *Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges, Vol. II: Cost Assessment and Impacts* (16) describe in detail the available sources of this information and the procedures for its use.



LAND USE BREAKDOWN	% OF AREA		
	COMBINED SEWERS	SEPARATE STORM SEWERS	NATURAL CONVEYANCE
RESIDENTIAL LO-DENS MED-DENS HI-DENS COMMERCIAL INDUSTRIAL RESIDUALS DISPOSAL OPEN			

TOTAL AREA ____________

FIGURE 3-4
DRAINAGE BASIN CHARACTERISTICS

The amount of runoff from storms and the pollutant loads associated with this runoff are determined by three basic elements:

1. Rainfall
2. Land use
3. The extent and type of stormwater collection and conveyance systems.

Each methodology described in this chapter employs a procedure to calculate flow and loads based on these inputs. The more sophisticated the methodology, the greater the detail required for the characterization of the drainage area. Any methodology may use initial estimates for relationships which convert rainfall and land use data into runoff flows and loads. Specific local data are needed to confirm or refine these relationships.

3.4.1 Identification of Appropriate Methodology

In general, there is no single methodology which is uniquely appropriate for the assessment of urban storm pollutant loadings in all 208 areas. The utility of each method is dictated by many factors, some of which include:

1. Local conditions
    a. land use
    b. conveyance system
    c. seasonal variation of rainfall
2. Availability of local data
    a. water quality data
    b. hydraulic data
    c. raingage data
    d. demographic data
3. Type of receiving water
    a. stream
    b. estuary
    c. lake
    d. coastal water

4. Water quality problems
    a. dissolved oxygen
    b. public health
    c. eutrophication
    d. other (TDS, TSS, etc.)
5. Time scale of water quality problems
    a. transient (hour, days)
    b. longer term (month, season, year)
6. Decisions involved
    a. feasibility of control
    b. economic risk
    c. environmental risk
7. Study constraints
    a. time
    b. cost

Specific methodologies which employ various levels of detail are used as part of the framework in which an urban loading assessment is performed. Examples of appropriate methodologies for storm loads are presented and described later in this chapter. The transient storm loads generated by these methodologies, together with the continuous point loads, are then used to assess receiving water impacts, as described in Chapter 5.

3.4.1.1 Selection of Suitable Estimation Procedures

The methods which are available to characterize and quantify stormwater loads all include the following essential elements:

1. Rainfall
2. Drainage basin characterization
3. Runoff quality and flow characterization

A major difference between the available methods lies in the detail in which the elements are represented. High levels of detail in the analysis require more definition of the drainage basin along with an associated increase in input data requirements. All of the methods attempt to describe the relationship between the runoff load and the various elements which influence it. A partial list of these elements includes:

1. Separate or combined sewer system
2. Collection system characteristics
3. Areal variability of rainfall
4. Rainfall intensity
5. Rainfall duration
6. Time between storms
7. Degree of imperviousness of drainage area
8. Drainage basin slope
9. Soil type, vegetative cover, erosion control practices
10. Land use: commercial, industrial, residential, open space, etc.
11. Population density
12. Surface pollutant accumulation and decay rate
13. Street cleaning frequency

Some of the simpler methods use empirical coefficients which aggregate many of the above influences. Other more sophisticated methods attempt to provide refined loading estimates by incorporating cause-effect relationships for the above elements.

Examples of more sophisticated simulation models which have been applied to estimate stormwater loads include: NPS Model, STORM, SWMM (continuous version). These and other applicable models are included in a discussion presented in Appendix A (NPS Model is discussed in Chapter 4) which describes the salient features of each model and its applicability for estimation of storm loads and receiving water impact.

The notable aspect of each of the models listed above is that they are continuous simulators. That is, they re-enact the stormwater process (the sequence of storm events over some extended period of time). They do not concentrate on single storm events. It is a knowledge of this event sequence and its impact, which often provides the best information and perspective for assessment studies.

Any method requires calibration before it can be used reliably. That is, samples of the runoff must be collected for a sufficient number of runoff events covering a variety of conditions so that consistent cause-effect relationships can be established. Once calibrated and verified, the methods can be used to make estimates of loads beyond the limited data set used in the calibration-verification procedure.

Where local data needed to calibrate the above models is lacking, estimates or default values for essential parameters can be used for the characterization of the cause-effect relationships in the models. It is well to recognize, however, that the default values were developed based on experience in a particular study area and are not universally applicable. Local effects and conditions have a significant influence, and without at least some local data for comparison, high degrees of confidence in calculated results may not be warranted.

Two simplified approaches to the characterization of storm loads are described in detail in this chapter. One is a simulation approach which represents loadings by storm events. The other estimating procedure presents a purely statistical method for the assessment of runoff and treatment. Each incorporates a level of detail which is appropriate for assessment studies, and permits the examination of long term characteristics. While both permit estimates to be made without local data, the use of such data for calibration to local rainfall, runoff and quality characteristics will produce load estimates with a higher degree of confidence.

3.4.1.2 Levels of Accuracy Required in Storm Load Characterization

At each level of detail in the stormwater load characterization (e.g. yearly, seasonally, monthly, event by event, etc.) described in Figure 3-1, there is a certain level of accuracy provided by the various calculation techniques. Two types of accuracy can be considered in applying available techniques: (a) event accuracy and (b) statistical accuracy for a long term sequence of events.

Many simulator models attempt to correctly relate phenomena in the drainage area to their associated effect on stormwater loads. They require calibration to define a consistent set of coefficients which establish the magnitude of the parameters in the cause-effect relationships. In order to estimate these parameters, a sufficient number of stormwater overflow events are monitored. Then the model coefficients are estimated and adjusted until there is a good agreement between the predicted load distributions within individual events and the actual observed values. The simulator is then considered calibrated. If other events with different rainfall properties agree equally well with observed data, the simulator can be considered to be verified. A good calibration requires comparison with a number of significantly different storm events, such that there is a reasonable agreement between actual and calculated distributions of loads for events which cover a wide range of relevant magnitudes. This calibration may be quite difficult in that it requires substantial amounts of data on drainage area characteristics, storm flow, and quality; all for a sufficiently large number of events. Where the calibration is accomplished for only a few events, the confidence in the prediction would be high only for conditions similar to those used in the calibration. For significantly different event conditions, such as more or less intense storms, differing durations, longer or shorter periods between storms, etc., there would be less confidence in the prediction.

Event accuracy reflects a very high level of definition of virtually all of the significant cause and effect relationships which influence stormwater loads. Both data requirements and the analytical effort required to achieve a satisfactory degree of event accuracy are high.

Statistical process accuracy is directed toward the accurate statistical representation of stormwater loads over extended time periods. Individual storm events may be either underestimated or overestimated, however when the statistical summary of the long term sequence of events can be appropriately characterized for a period of interest, the model output can be considered to have statistical accuracy.

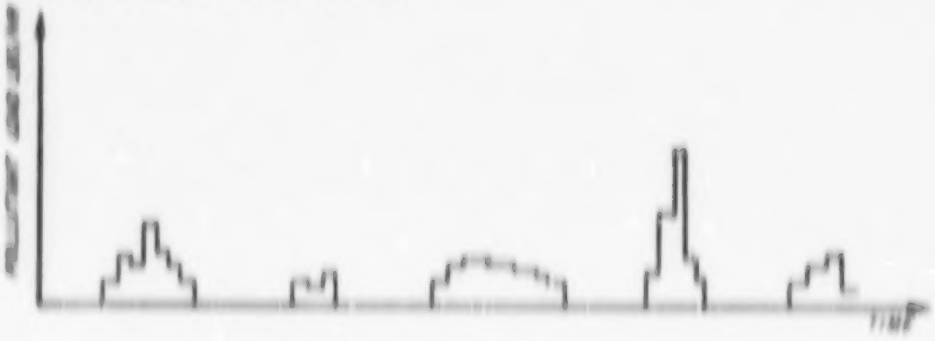
Load characterizations of this type are often appropriate in the second level of problem assessment since at this level of analysis it is not always necessary to have an accurate and complete understanding of the mechanisms which actually determine storm loads. Statistical summaries which include the mean, the coefficient of variation, and the frequency distribution of the load are sufficient information for a reasonable and complete assessment of present conditions, and also for an estimate of the effect of certain control measures.

In some cases, the areal variability of rainfall and the insufficient number and distribution of rain gages introduce errors in storm event calibration. Such errors become less important, however, when the models are directed toward reproduction of the longer term process statistics rather than toward individual events. The "continuous" versions of some of the available simulator models are intended to stress the longer term effects rather than the detail of single events. Figure 3-5 illustrates a manner in which loads from a long term sequence of storm events may be analyzed to summarize those features of the storm process which are significant for an assessment study. Pollutant loads generated by individual storm events are estimated on the basis of the properties of the storm event causing the runoff. The magnitude and time of occurrence are determined as illustrated by Figure 3-5(a). Statistical procedures may be used to develop a probability density function representing the frequency of occurrence of loads of various magnitude, as illustrated by Figure 3-5(b). Providing the period of record used for analysis is long enough to yield statistically significant results, this analysis may be made for annual periods, specific seasons of the year or individual months of interest. Additional discussion on the development of these probability density functions is provided in Sections 3.4.3 and 3.4.4.

3.4.1.3 Levels of Spatial Detail Required in Storm Load Characterization

Another important aspect of stormwater load characterization is the spatial detail with which loads are defined. There are situations where either the event accuracy or the statistical process accuracy will be reduced because the load estimating methodology does not adequately describe the spatial distribution of stormwater loads from an area. Included among the conditions which will require increased levels of detail in the definition of waste load input locations are the following:

(a) SINGLE EVENT DISTRIBUTION



(b) STATISTICAL REPRESENTATION OF LOADING FROM SEVERAL EVENTS

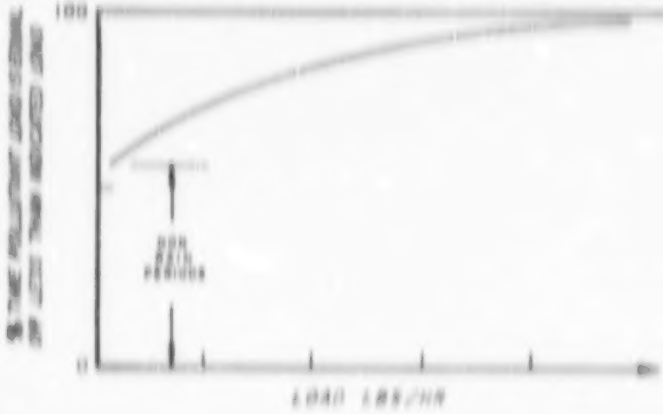


FIGURE 3-5

REPRESENTATIONS OF A LONG TERM SEQUENCE OF STORM POLLUTANT LOADS

1. Aggregating smaller sub-catchments into a single large drainage area may be difficult for a combined sewer collection system with multiple overflow locations. The estimation of an "average" interceptor capacity representative of the entire drainage area will introduce error in the load estimates for some areas.
2. Storms in an area may be highly localized and result in significant areal variability of rainfall. The delineation of smaller sub-catchments will be necessary to increase the accuracy of load estimates in some cases.
3. For some receiving waters, it will be necessary to characterize storm loads according to their actual point of discharge, in order to make an accurate assessment of the impact of these multiple loads on receiving water quality.

There are, however, conditions under which it is appropriate to ignore such spatial detail without introducing unacceptable error into the estimation of storm loadings. This is particularly true for analyses being performed at an assessment level of detail and, for water quality analyses where longer term statistical process accuracy is the objective and where the assumption that the rainfall occurs uniformly throughout the entire study area is reasonable.

Due to the areal distribution of rainfall, different sub-catchments of a drainage basin may have considerably different runoff loads during a particular storm. The longer term frequency distributions of the rainfall on each of the subcatchments, however, are more likely to be similar, and a larger area may be aggregated when determining long term runoff flows and loads. Caution must be used, however, when aggregating different subcatchments for the purpose of determining runoff flows and loads during storms. The assumption that the rainfall is falling uniformly and simultaneously throughout the area may cause a large overestimation of the runoff flow and load that occurs during storms.

For impacts which are long term in nature, or for receiving waters (tidal estuaries, for example) where significant mixing takes place, it is often adequate to ignore some of the spatial detail, even for analyses with higher levels of refinement.

Figure 3-6 illustrates schematically the type of spatial aggregation of individual loads which can often be made in assessment studies utilizing the level of refinement discussed in this chapter. The loads from subcatchment sections one through five may be aggregated and assumed to enter the receiving water at a single location.

3.4.2 Characterization of Rainfall-Runoff Relationship and Runoff Quality

The key element in making reliable storm load estimates with any of the available methodologies is the determination of appropriate relationships for the study area which describe the amount of rainfall which will leave the area as runoff and the pollutant concentrations associated with the runoff.

Both the statistical method and the simulator method later described in this chapter require estimates of runoff quantity and quality. Techniques for determining both an average runoff coefficient and representative pollutant concentrations in storm flows for use in both these methods are presented in this section.

3.4.2.1 Estimation of Runoff Coefficient

The volumetric runoff coefficient, C_V, measures the fraction of the storm volume which reaches the conveyance system as runoff. Because the use of a volumetric runoff coefficient aggregates the combined effects of variable storm properties and drainage basin characteristics, it is not treated as a constant, but as a random variable. The purpose of this section is to determine an average value, C_V, which may be employed in storm load assessments.

It is preferable to estimate C_V by comparing raingage data to runoff monitored during corresponding storms. Flow measurements should be taken within the sewer system and/or the natural conveyance channels. Flow data that are developed can include faulty data because of measuring

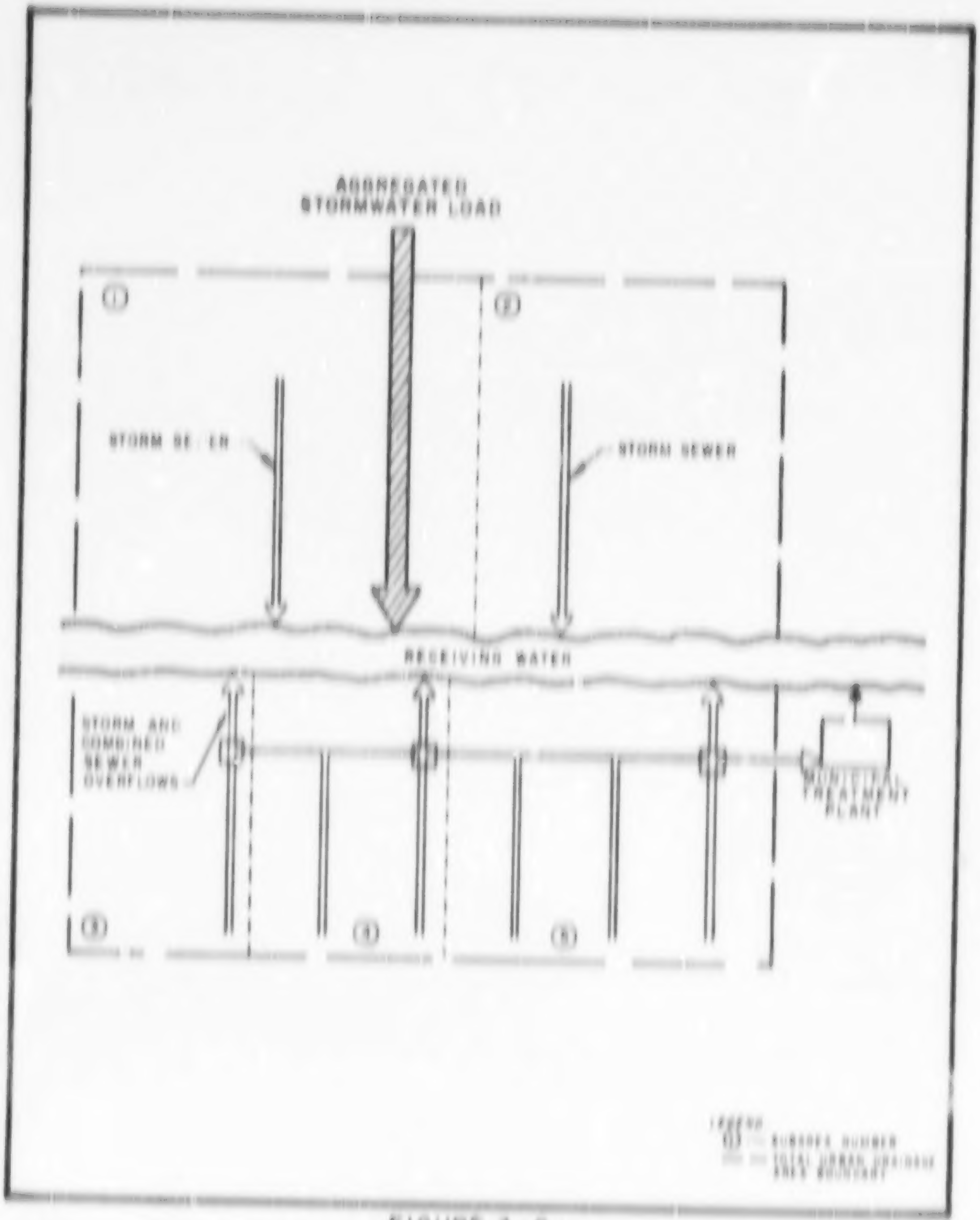

AGGREGATED STORMWATER LOAD
①
②
STORM SEWER
STORM SEWER
RECEIVING WATER
STORM AND COMBINED SEWER OVERFLOWS
MUNICIPAL TREATMENT PLANT
③
④
⑤
LEGEND
① = SUBAREA NUMBER
= TOTAL URBAN DRAINAGE AREA BOUNDARY

FIGURE 3-6
COMPARISON OF SPATIAL DETAIL
IN STORMWATER LOADING CHARACTERIZATION

equipment and maintenance weaknesses, therefore data and maintenance records should be screened carefully to identify such occurences. It is incorrect to assume that, because two significantly different runoff volumes are recorded for similar rainfall events, the equipment is necessarily faulty. The two storms may have occured with different antecedent soil conditions or with a different areal extent and spatial distribution of rainfall with respect to the raingage recording the events.

A sufficiently large number of observations of runoff quantity for at least one representative location for which drainage area characteristics are well known would be required to develop a representative value for the average runoff coefficient, C_V. In a statistical evaluation of rain events performed by the National Oceanographic and Atmospheric Administration (NOAA), one of the findings was that there is a 90 percent confidence level in the expectation that 85 percent of the various intensity and duration rain events for a given location will be experienced within a 2.8 year period (20). It would therefore be a rather long term and costly project to study even most of the possible rainfall events. Some decision must be made on how long a study period should last and how many events should be monitored.

From statistical sampling theory, the Central Limit Theorem states that the distribution of sampled averages tends to become normal as the number of samples increases, no matter what the distribution of the variable being sampled (21). This property may be used to estimate the number of storms necessary for an adequate estimate. This number is dependent upon the variation of the parameter being measured (in this case the runoff coefficient), the maximum desired error in the estimate of the average, and the confidence that one has that the sampled average falls within the particular range. Figure 3-7 shows the relationship between the number of storms monitored and the resulting level of accuracy. The curves presented are based on a coefficient of variation of 0.75 for the runoff coefficient, which appears to be a reasonably conservative estimate based on observed data (22). In general, 20 to 40 storms will provide adequate representation.

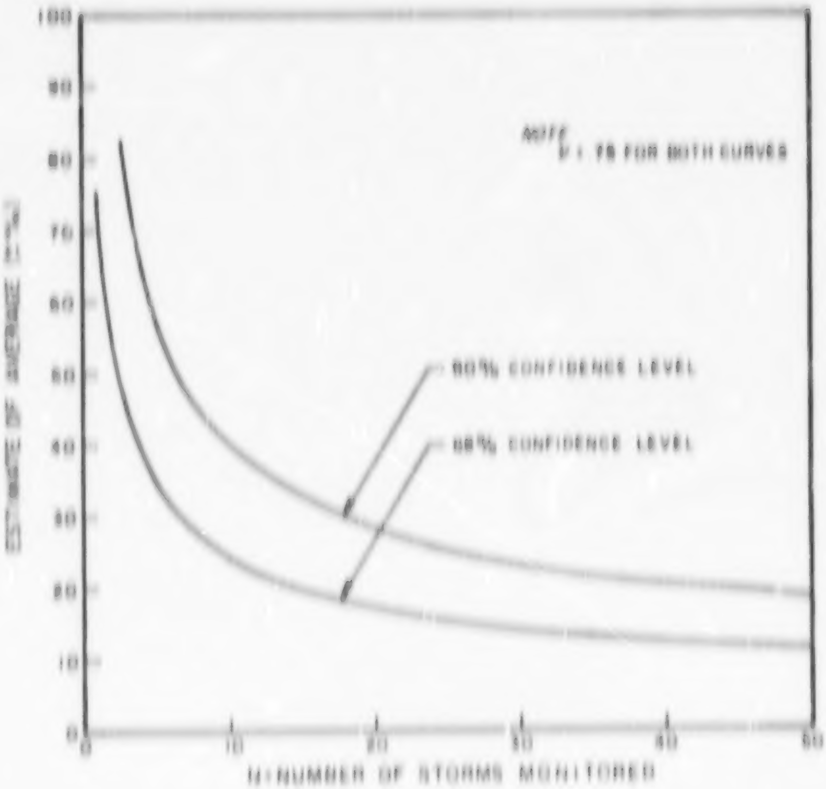


FIGURE 3-7
ERROR IN ESTIMATE OF AVERAGE
VERSUS NUMBER OF STORMS MONITORED

When extensive monitoring is not feasible for a study
data is not available at the time an analysis is made, estimates may be made from land use and drainage basin characteristics. The greater the percentage of impervious surfaces in a watershed, the greater will be the runoff for a given size storm. This is due to the reduction in the amount of rainfall lost to infilitration. Relationships between the percent impervious area and the runoff coefficient have been developed from the analysis of published data and are shown in Figure 3-8. These include results averaged from eight cities (22) (the solid curves in Figure 3-8) and the equation developed for use in the STORM simulation model (24,25). The volumetric runoff coefficient, C_v, is the ratio of the runoff volume to the volume of the rainfall, and therefore accounts for depression storage as well as infiltration. The equation in the STORM simulation model, uses an average instantaneous runoff coefficient and does not account for depression storage. In this model, a separate adjustment is made to account for depression storage, as follows (15):

Land Use	Depression Storage (in)
Impervious	0.0625
Pervious	0.25

For a given land use, the area weighted depression storage, (DS), in inches, is:

$$DS = 0.25 - 0.1875 \text{ (Percent Impervious Area/100)} \qquad (3\text{-}1)$$

When using the STORM equation, the depression storage should be subtracted from the rainfall volume before multiplying by the runoff coefficient. However, the depression storage correction may be too refined at this level of analysis due to the variation in the data upon which both the estimates of the volumetric and the instantaneous runoff coefficients are based.

The percentage of impervious area in a drainage basin may be determined by examining aerial photgraphs or detailed land use plans. This may be a long and tedious task, however, particularly for large drainage areas. Estimates may also be made on the basis of the general fraction of land in different land use categories. Specific land use classifications are

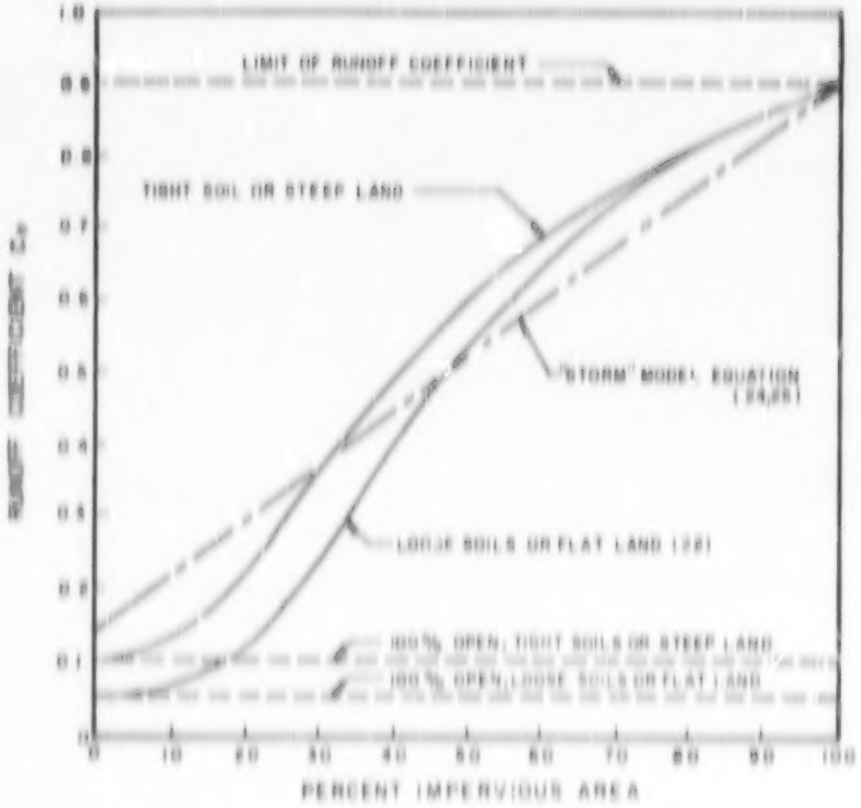


FIGURE 3-8
RUNOFF COEFFICIENT DETERMINATION
FROM LAND COVER INFORMATION

assigned an average percent impervious area as shown below. The indicated values or other handbook estimates (26) may be modified or refined on the basis of local information, past experience or field inspection surveys.

Land Use Category	Percent Impervious Area
Residential	
Low Density	20
Medium Density	40
High Density	60
Commercial	80
Industrial	70
Institutional, Public	30
Open, Undeveloped	0

The percent impervious area for the entire drainage area is calculated by taking a weighted average of the individual components of the area. For example, assume an area has the following land use characteristics:

Low Density Residential	30%
Medium Density Residential	20%
Comercial	10%
Industrial	10%
Institutional, Public	5%
Open, Undeveloped	25%
Total	100%

The overall percent impervious area would be:

$$\begin{aligned}\text{Percent Impervious Area} &= (0.30) \times (20) + (0.20) \times (40) \\ &+ (0.10) \times (80) + (0.10) \times (70) \\ &+ (0.05) \times (30) + (0.25) \times (0) \\ &= 30.5\%\end{aligned}$$

This value would be used in Figure 3-8 to determine the average runoff coefficient, C_V.

If information on the land use categories cannot be obtained, the percent imperviousness in developed areas may be estimated from the population density. Graham et al. (Washington, DC) (25), the American Public Works Association (18) and Stankowski (New Jersey) (27) have developed equations to predict imperviousness as a function of population density. The imperviousness is to be estimated for the developed portion of the urbanized area only. The weighted average imperviousness and population density were also calculated for nine Ontario cities(28). These results are plotted on Figure 3-9 along with the three estimating curves (15). If the New Jersey data, which is based on 567 municipalities, is selected as a reasonable guideline, the equation used to estimate imperviousness is:

$$\text{Percent Impervious Area} = 9.6\ PD_d^{\ (0.573-0.0391\ \log_{10}PD_d)} \qquad (3\text{-}2)$$

where:

PD_d = population density in developed portion of the urbanized area (persons/acre).

The percent impervious area is used to obtain the runoff coefficient, C_V, from Figure 3-8.

Note that individual estimates of the runoff coefficient should be made for areas served by combined sewers, saparate sewers or natural conveyance. This is because significant differences in pollutant concentrations are found in the storm flows which enter receiving waters from such areas.

The final component of flow which may be of interest in combined sewer systems is the dry weather flow. This may be estimated as 100 gallons per person-day, when more area specific data is not available.

3.4.2.2 Estimation of Runoff Pollutant Concentrations

The most reliable estimates of runoff pollutant concentrations are obtained from extensive local monitoring programs. The most comprehensive quality data from a monitoring program would reflect the changes in concentration during various storm events for each overflow location.

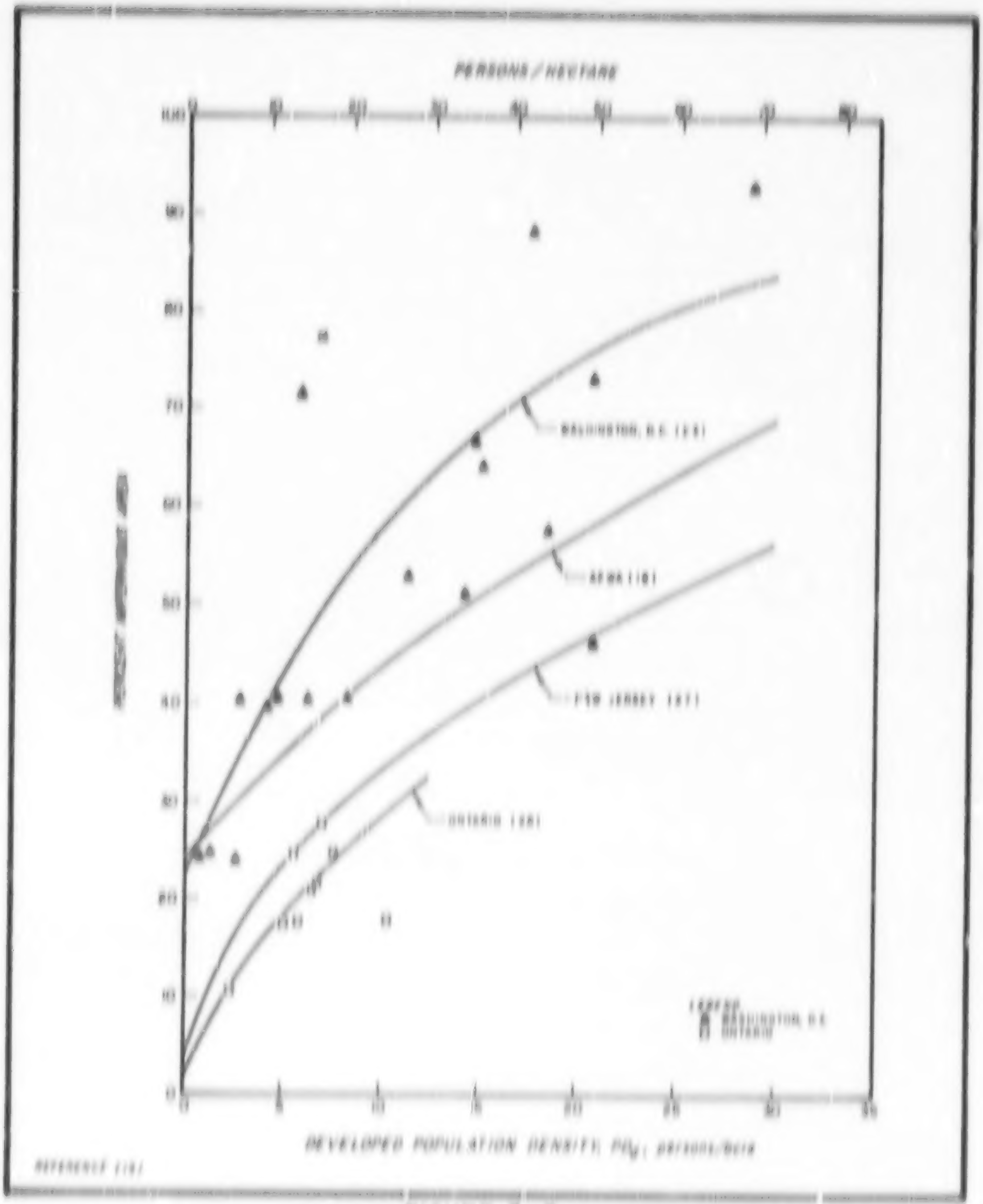


FIGURE 3-9
IMPERVIOUSNESS AS A FUNCTION OF
DEVELOPED POPULATION DENSITY

information on variations in quality within a storm event will help to identify the magnitude of the first-flush phenomenon. The measurement of quality for each separate area would reflect the impact of the mix of various land uses on the wastewater loads discharged.

The use of composite or grab samples from overflows may be substituted in an assessment study for the complete time-history measurements which would be costly and time consuming. This may cause a distortion in the results, because the first-flush phenomenon, if it occurs, is not acknowledged. The occurrence of a first-flush phenomenon is dependent upon the size and characteristics of a catchment area and storm characteristics. Grab or composite sampling will provide an insight into the quality of the overflow only on an event averaged basis.

A sufficient number of storms must be monitored to adequately characterize pollutant concentrations. The guidelines presented in Section 3.4.2.1 on the runoff coefficient may be used to determine the number of storms to be monitored for quality estimates for specific catchments. Since observed data (22) suggests that a reasonable estimate of the variation of runoff concentrations between storms in a specific catchment is also on the order of 0.75, Figure 3-7 can be used to estimate a general requirement for samping 20 to 40 storms.

A sufficiently large series of measurements at a few overflow locations, representative of different land uses or degrees of imperviousness, can then be used to synthesize results for the remaining catchments.

When time and budget constraints make an extensive monitoring program infeasible, estimating procedures may be used to establish representative concentrations of pollutants of interest. The most direct estimates of the average runoff concentration, $\bar{C}$, may be made from Table 3-3 (previously presented in Chapter 2). Runoff concentrations of six major pollutants were monitored for a number of cities with either separate or combined sewers, and the averages of these concentrations reported for each city (22). The mean and standard deviation of these site-specific average concentrations are found in Table 3-3. The standard deviation listed in Table 3-3 reflects differences between cities and should not be used to

TABLE 3-3

SUMMARY OF STORMWATER POLLUTANT CONCENTRATIONS(22)

	STORMWATER OVERFLOW CONCENTRATIONS			
	SEPARATE DRAINAGE AREAS[a]		COMBINED AREAS [b]	
POLLUTANT [c]	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
BOD_5	27	25	108	36
COD	205	118	284	110
S.S.	608	616	372	275
Total Coliforms [d]	$3x10^5$	-	$6x10^6$	-
Total Nitrogen (as N)	2.3	1.4	9	6
Total Phosphorus (as P)	0.5	0.4	1.8	2.9

(a) Summary of 20 cities, storm sewers and unsewered areas

(b) Summary of 25 cities, combined sewer areas

(c) All unites mg/l except coliforms, MPN/100 ml

(d) Geometric mean

estimate v_c, the variation of the pollutant concentrations in the runoff from different storms in a given study area. It should be used only as a guide for estimating the mean runoff concentration, $\bar{c}$. One may choose $\bar{c}$ equal to the mean for the many cities, or for a more conservative estimate of $\bar{c}$, the mean plus one standard deviation. For example, a value for Total Nitrogen for a combined sewered area may be chosen as $\bar{c}$ = 9 mg/l (as N), or more conservatively as $\bar{c}$ = 15 mg/l (as N).

Many attempts have been made to relate stormwater loads to land use as an alternative or possible refinement to the basis for estimating runoff quality summarized by Table 3-3. These have been somewhat successful, but there is usually a very high average error of estimate in the prediction; that is, for a given land use pattern, the runoff quality still varies greatly. Despite this limitation, the ability to relate runoff pollutant concentrations to land use provides the ability to predict the magnitude of future runoff load changes due to changes in land use. A general procedure for predicting runoff quality from land use and population density, developed on a nationwide basis, is outlined as follows. This procedure is based on load estimates developed in reports for the Environmental Protection Agency (15,16). In these studies, loads were determined as follows:

$$M_s = \alpha(i,j) \cdot P \cdot f_1(PD_d) \cdot \gamma \qquad (3\text{-}3)$$

$$M_c = \beta(i,j) \cdot P \cdot f_1(PD_d) \cdot \gamma \qquad (3\text{-}4)$$

where:

M_s = pound of pollutant (j) from land use (i) with separate and unsewered conveyance (lbs/acre-yr)

M_c = pound of pollutant (j) from land use (i) with combined sewer conveyance (lbs/acre-yr)

$\alpha(i,j)$ = constant for pollutant (j) and land use (i) with separate and unsewered conveyance (lbs/acre-in)

$\beta(i,j)$ = constant for pollutant (j) and land use (i) with combined sewer conveyance (lbs/acre-in)

P = annual precipitation (in/yr)

$f_1(PD_d)$ = population function

PD_d = population density (persons/acre)

γ = street sweeping effectiveness factor

Equations (3-3) and (3-4) permit an estimate of BOD_5, SS, VS, PO_4, and N loads as a function of land use, type of sewer system, population density, and street sweeping frequency.

Table 3-4 shows the land use categories and pollutants.

TABLE 3-4

LAND USE AND POLLUTANTS

Land Uses		Pollutants	
i = 1	Residential	j = 1	BOD_5, Total
i = 2	Commercial	j = 2	Suspended Solids (SS)
i = 3	Industrial	j = 3	Volatile Solids, Total (VS)
i = 4	Other Developed Areas	j = 4	Total PO_4 (as PO_4)
		j = 5	Total N (as N)

The runoff load from residential areas will increase with increasing population density. The population function is shown below.

for i = 1 (Residential): $p_1(PD_d) = 0.142 + 0.218\ (PD_d)^{0.54}$ (3-5)

for i = 2 or 3 (Commercial or Industrial): $p_1(PD_d) = 1.0$ (3-6)

for i = 4 (Other Developed Areas): $p_1(PD_d) = 0.142$ (3-7)

The intercept for residential areas (0.142) was determined based on data for open space. The exponent (0.54) is based on the exponent of the STORM imperviousness equation at a population density of 8 persons per acre. Lastly, the coefficient (0.218) is based on an average of data points with PD_d ranging from 5 to 15 persons per acre to yield a $p_1(PD_d)$ of 0.895 at 10 persons per acre.

The street sweeping effectiveness factor, γ, was derived by making numerous runs of STORM with varying street sweeping frequencies (15). The factor is a function of the street sweeping interval, N_s (days) and is defined by equation (3-8).

$$\gamma = \frac{N_s}{20} \text{ if } 0 \leq N_s \leq 20 \text{ days}$$
$$\gamma = 1.0 \text{ if } N_s \geq 20 \text{ days} \qquad (3\text{-}8)$$

Table 3-5 lists α and β factors that are used in quations (3-3) and (3-4) for the loading analysis. The methodology thus far presented is for the determination of yearly stormwater loads. Both estimating procedures presented in this Chapter require average runoff concentrations. To provide this Equations (3-3) and (3-4) for the runoff load were converted to estimate the runoff concentration.

The resulting equations are:

$$\bar{C}_s = a(i,j) \cdot p_1(PD_d) \cdot \gamma \qquad (3\text{-}9)$$
$$\bar{C}_c = b(i,j) \cdot p_1(PD_d) \cdot \gamma \qquad (3\text{-}10)$$

where:

$\bar{C}_s$ = concentration of pollutant (j) from land use (i) with separate and unsewered conveyance (mg/l)

$\bar{C}_c$ = concentration of pollutant (j) from land use (i) with combined sewer conveyance (mg/l)

$a(i,j)$ = constant for pollutant (j) and land use (i) with separate and unsewered conveyance (mg/l)

$b(i,j)$ = constant for pollutant (j) and land use (i) with combined sewer conveyance (mg/l)

The factors a and b were determined from the following conversion:

$$a(i,j) = (\alpha(i,j) \cdot F)/C_v(i) \qquad (3\text{-}11)$$
$$b(i,j) = (\beta(i,j) \cdot F)/C_v(i) \qquad (3\text{-}12)$$

where:

F = 4.42, a constant (mg/l)/(lb/acre-in)
$C_v(i)$= runoff coefficient for land use (i)

$C_v(i)$ was estimated from the percent imperviousness generally associated with each land use, as described in Section 3.4.2.

for i = 1 (Residential) $C_v(1) = 0.30$
for i = 2 (Commercial) $C_v(2) = 0.70$

TABLE 3-5

$\alpha^{(a)}$ AND $\beta^{(b)}$ FACTORS$^{(c)}$

	Pollutant				
Land Use	BOD_5 (j=1)	SS (j=2)	VS (j=3)	PO_4 (j=4)	N (j=5)
i=1 Residential(α)	0.799	16.3	9.45	0.0336	0.131
i=2 Commerical(α)	3.20	22.2	14.0	0.0757	0.296
i=3 Industrial(α)	1.21	29.1	14.3	0.0705	0.277
i=4 Other Developed Areas(α)	0.113	2.70	2.6	0.00994	0.0605
i=1 Residential(β)	3.29	67.2	38.9	0.139	0.540
i=2 Commerical(β)	13.2	91.8	57.9	0.312	1.22
i=3 Industrial(β)	5.00	120.0	59.2	0.291	1.14
i=4 Other Developed Areas(β)	0.467	11.1	10.8	0.0411	0.250

(a) Applies to separate and unsewered drainage areas

(b) Applied to combined drainage areas

(c) Units are lb/acre-in

for i = 3 (Industrial) $C_v(3) = 0.60$

for i = 4 (Other Developed) $C_v(4) = 0.10$

Table 3-6 lists the converted a and b factors that are used in equations (3-9) and (3-10) for the determination of runoff concentrations. The a and b factors of Table 3-6 were calculated with the assumed runoff coefficient for each land use, $C_v(i)$ and may be adjusted according to equations (3-11) and (3-12) if it is felt that a different runoff coefficient is appropriate for the particular land use in the given study area.

To illustrate the use of this methodology, assume that an area has combined sewers and portions of the area are residential (with $PD_d = 20$), commercial, and industrial. If the street sweeping interval is greater than 20 days, the BOD_5 pollutant concentration for each area may be calculated as follows:

Residential: $p_1(PD_d) = 0.142 + 0.218\ (20)^{0.54}$

$p_1(PD_d) = 1.24$

$\bar{c}_u = (48.6) \cdot (1.24) = 60.3$ mg/l BOD_5

Commercial: $\bar{c}_u = 83.2 \cdot (1) = 83.2$ mg/l BOD_5

Industrial: $\bar{c}_u = 36.7 \cdot (1) = 36.7$ mg/l BOD_5

Other: $\bar{c}_u = 20.6 \cdot (.142) = 2.9$ mg/l BOD_5

The concentration calculated for each land use category may then be assigned to the corresponding runoff flow from that area.

Note that the values obtained from this methodology represent averages of widely scattered data, and one should not be surprised if the actual monitored runoff concentrations for a particular area differ noticeably from those calculated. The concentrations calculated with the EPA land use-population density approach differ from the results summarized in Table 3-3. For example, in the land use approach all combined sewer concentrations are assumed to be 4.12 times greater than the separate sewer concentrations, while Table 3-2 indicates higher SS concentrations in separate sewer areas.

TABLE 3-6

$a^{(a)}$ AND $b^{(b)}$ FACTORS$^{(c)}$ FOR GIVEN $C_v(i)$

Land Use	$C_v(i)$	Pollutant BOD_5 (j=1)	SS (j=2)	VS (j=3)	PO_4 (j=4)	N (j=5)
i=1 Residential(a)	0.30	11.8	240	139	0.50	1.9
i=2 Commerical(a)	0.70	20.2	140	88	0.48	1.9
i=3 Industrial(a)	0.60	8.9	214	105	0.52	2.0
i=4 Other Developed Areas(a)	0.10	5.0	119	115	0.44	2.7
i=1 Residential(b)	0.30	48.6	989	574	2.04	8.0
i=2 Commerical(b)	0.70	83.2	578	364	1.97	7.7
i=3 Industrial(b)	0.60	36.7	883	134	2.14	8.4
i=4 Other Developed Areas(b)	0.10	20.6	492	473	1.81	11.0

(a) Applies to separate and unsewered drainage areas

(b) Applied to combined drainage areas

(c) Units are mg/l

The method presented for relating runoff concentrations to land use and drainage basin characteristics was developed with correlations to nationwide data. These estimates may be further refined with local runoff quality data. Regression techniques have been used to relate runoff concentrations to local land use characteristics and storm parameters with varying degrees of success (29,30,31). Note that unless statistically significant correlations are obtained, regression equations will provide no more accuracy than the simpler techniques presented.

The estimations thus far introduced are for the mean runoff concentration, $\bar{c}$. The other value of interest is the variation of the runoff concentration (between storms), v_c. Preliminary analyses have indicated v_c ranging from 0.50 to 1.00. For an initial estimation, a conservative value of $v_c = 1.00$ may be selected (22).

Once representative estimates of the runoff coefficient and the pollutant concentrations have been determined, the storm loading assessment may proceed. Two particular approaches, a statistical method and a simulator method will now be presented.

3.4.3 A Statistical Method for the Assessment of Storm Loads

A simplified statistical approach to stormwater loading problems is described in this section. The statistical method for the assessment of runoff and treatment (22) is a flexible tool for the initial analysis of stormwater loads, their impacts, and alternative control strategies. It is a methodology rather than a specific computer model with fixed inputs, algorithms, and results. The basic statistical attributes of the rainfall-runoff process are used to provide simple initial estimates of the quantities pertinent to stormwater assessments. The statistical method may be applied initially without extensive data requirements and sophisticated urban runoff models. More complex models may be subsequently incorporated if more refined estimates are needed.

The statistical method begins with an analysis of rainfall, the basic driving force in the generation of stormwater loads. Raingage data is analyzed to provide a statistical summary of the rainfall process. The characteristics of the drainage area are then used to determine the runoff flow and associated pollutant load. This load may be modified by treatment or storage; either by the existing conveyance system, or by special stormwater control facilities. The stormwater loads thus developed are subsequently applied to the receiving water to determine the severity of their impacts (Chapter 5).

Initial storm load assessments require a broad summary of the rainfall-runoff process. The statistical method performs this summary by determining the statistical properties of the relevant storm characteristics. The simulator method presented in Section 3.4.4 operates directly on the actual rainfall record to perform the assessment. Both methods determine the expected frequency of various storm load magnitudes. If the probability distribution functions of the storm characteristics are well represented by the theory of the statistical method, the results of the statistical and simulator methods will be similar. The statistical method provides a more general initial summary, while the simulator method allows for more specific analyses of temporal and spatial detail. The statistical method is outlined in Figure 3-10, and specific procedures for employing the methodology will now be presented.

3.4.3.1 Statistical Rainfall Characterization

Hourly rainfall data is obtained for a minimum of five years of record to provide sufficient confidence in the rainfall characterization. Longer term records covering many years are preferable and are usually available for U.S. Weather Bureau Stations.

The hourly data are then summarized into storm events, each with an associated unit volume (v, in), duration (d, hr), average intensity ($i = v/d$, in/hr), and time since the previous storm (Δ, hr), measured from the midpoint of the successive storms. A storm definition must be established to determine when in the hourly record a storm begins and ends. Additional refinements may be added to include such things as snowfall, trace storms, or whatever appears appropriate for the study area (22). A computer program is available which reads hourly rainfall records, defines the end of a storm by a fixed number of consecutive

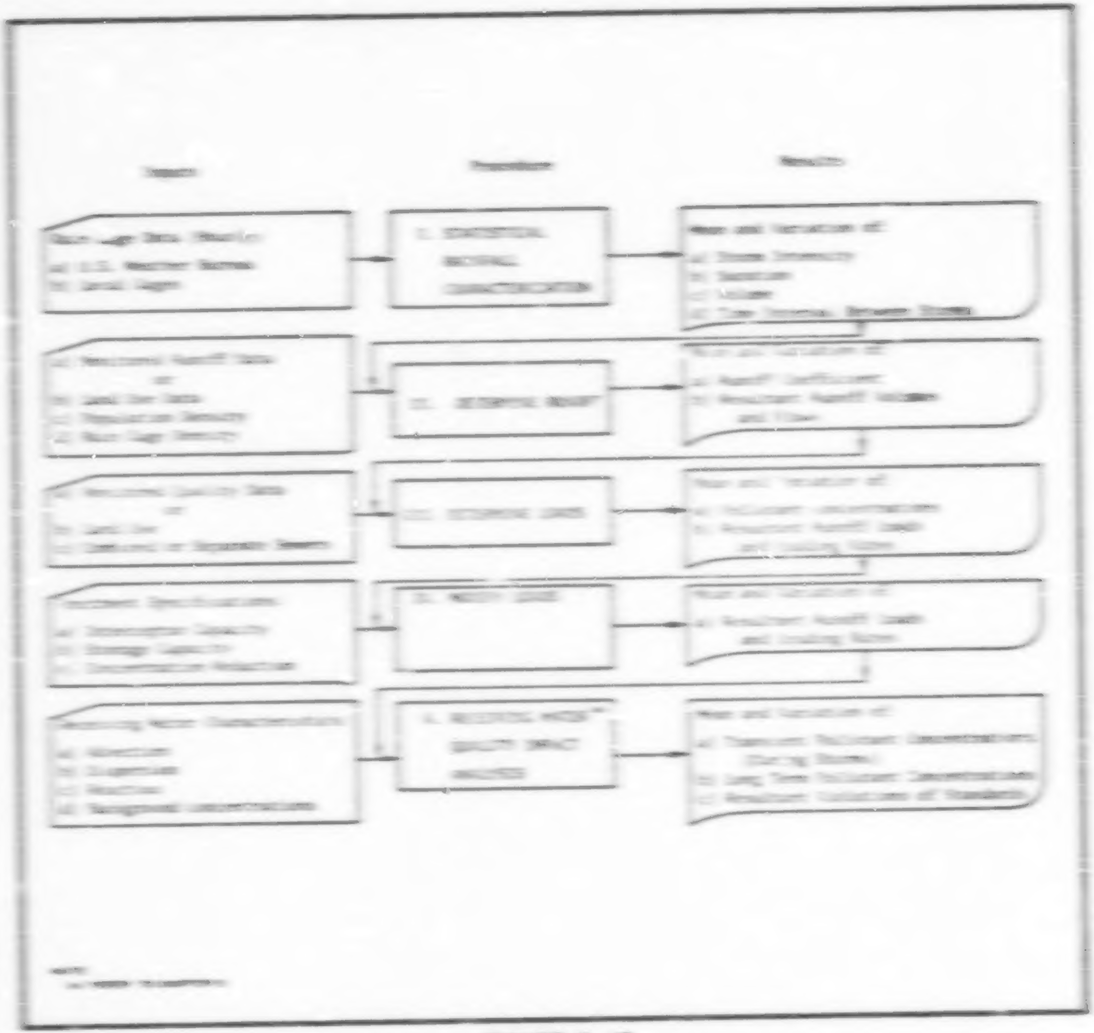


FIGURE 3-10
STATISTICAL METHOD FOR THE ASSESSMENT OF RUNOFF

hours without precipitation, includes all forms of precipitation and determines the relevant individual storm characteristics. This program is outlined in Appendix E which will be included in this manual at a later date.

The statistics of the storm parameters are then computed. The mean and the coefficient of variation of each parameter are determined: the mean is the arithmetic average; the coefficient of variation is defined as the standard deviation divided by the mean. The required statistics are summarized below.

Parameter	For Each Storm	Mean	Coefficient of Variation
Storm Intensity	i	I	ν_i
Duration	d	D	ν_d
Unit Volume	v	V	ν_v
Time Between Storms	δ	Δ	ν_δ

Note that if storm intensities and durations are independent, the mean storm volume, V, will equal ID. In many areas, they are not independent; for example, long less-intense storms tend to occur in the winter, and short more-intense storms tend to occur in the summer. In such cases, V will not equal ID. To avoid this potential error, the rainfall analysis program determines V for the individual storm volumes. If a particular season or period is considered critical due to adverse receiving water characteristics or greater pollutant accumulation rates, the representative summary may simply be made on the long term record of storms occurring during the selected season. The rainfall analysis program described in Appendix E provides monthly summaries which can be used to indicate and analyze seasonal characteristics.

Once the mean and the coefficient of variation of the rainfall characteristics have been determined, the cumulative density function may be developed. This is done by assuming that the rainfall parameters, storm intensity, i, duration, d, and time between storms, δ, are gamma distributed. Storm volume, v, would then have a distribution determined by the product of two gamma distributed random variables (i and d).

In practice, storm volumes have also been found to be fairly well represented by a gamma distribution.

The cumulative density function for a gamma distribution is shown in Figure 3-11. A number of graphs have been used because of the confusing manner in which the curves intersect. For example, if the variation of storm intensities determined from the statistical rainfall analysis is: $v_i = 1.00$, from Figure 3-11(a) the 90th percentile intensity would then be 2.3 times the mean intensity, I. In other words, ten percent of the storms have average intensities greater than 2.3(I). Interpolation may be used for intermediate values of variation.

The expected number of storms greater than a given value may then be calculated. The average number of storms occuring during a given period is first calculated:

$$\text{Average number of storms} = \frac{\text{Length of Period}}{\Delta} \qquad (3\text{-}13)$$

Then, for example, if the period of interest is one year and the statistical analysis indicates that the average time between storms, Δ, is 70 hours:

$$\text{Average Number of Storms} = \frac{1\ \text{year} \cdot 8760\ \text{hr/year}}{70\ \text{hr}} = 125$$

The expected number of storms greater than a given value is then the fraction of storms greater than the given value times the average number of storms. From the previous example, there will be (on the average) (0.10) · 125 = 12.5 storms per year with average intensities greater than 2.3(I).

3.4.3.2 Determination of Runoff

The rainfall parameters are next converted into runoff. The approach for initial assessments uses the average volumetric runoff coefficient, C_V. The runoff coefficient indicates the fraction of the storm volume which reaches the conveyance system:

$$V_R = 3630 \cdot C_V V A \qquad (3\text{-}14)$$

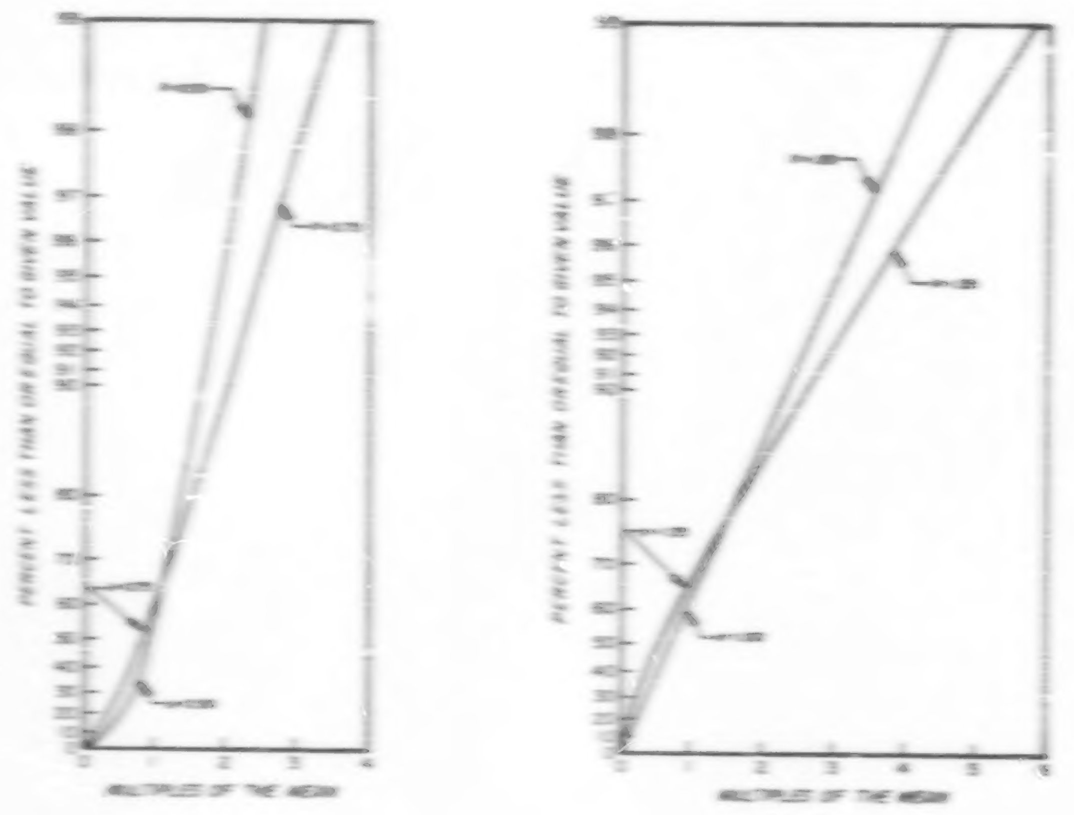


FIGURE 3-III(a)
CUMULATIVE DENSITY FUNCTION FOR
GAMMA DISTRIBUTION

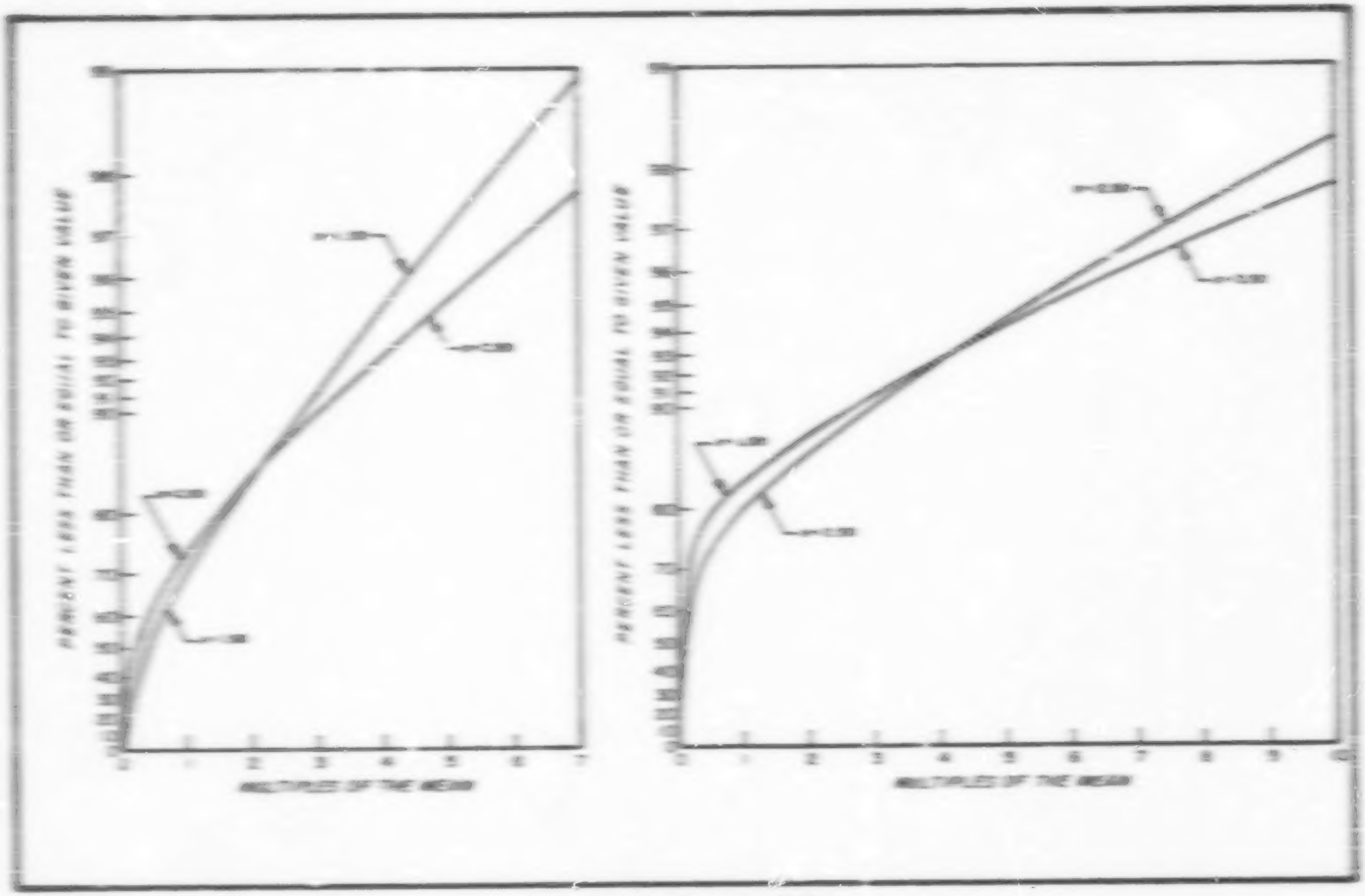


FIGURE 3-11(b)
CUMULATIVE DENSITY FUNCTION FOR GAMMA DISTRIBUTION

where:

V_R = mean runoff volume (ft^3)
V = mean unit rainfall volume (in)
A = drainage area (acres)
3630 = conversion factor to make units consistent (ft^3/acre-in).

The runoff coefficient may also be used to estimate the flow rate:

$$Q_R = C_V IA \tag{3-15}$$

where:

Q_R = mean runoff flow (cfs)
I = mean rainfall intensity (in/hr).

Depending upon the size and characteristics of the drainage basin, this may not acurately represent the attenuation of runoff beyond the end of a rain event. The value of Q_R will be overestimated for a large catchment area with a long time of concentration (the time it takes runoff from the farthest portion of the drainage area to reach a particular point in the receiving water). The estimate of Q_R may be too conservative even for an initial assessment. Unit hydrograph analysis (32) may provide guidance for evaluating or correcting the overestimation of Q_R. In some cases, however, more sophisticated models employing the time routing of flows may be required.

The best way to determine the runoff coefficient for a particular study area is to compare raingage data with the runoff monitored during corresponding storms. Sufficient data of this type is often not available, and in such cases estimates must be made based upon land use characteristics, either from land use surveys of the drainage area, or inferred from the population density. Procedures for estimating the average runoff coefficient, C_V, are presented in Section 3.4.2.1.

The fraction of the storm volume that is measured as runoff is not fixed. There is some variation in the runoff coefficient due to differences in soil moisture, soil infiltration rates or the available depression storage due to the influence of individual storm conditions and the length of time since the previous storm. There is also a variation in the measure of the runoff coefficient resulting from the variation from storm to storm in the amount of rainfall recorded at a point (raingage) versus the amount that actually falls over the entire catchment area.

Studies dealing with the relationship between point rainfall data and the areal distribution of rainfall (33-38) indicate that for many areas, point rain data will be representative of very large areas, when evaluated on a long term basis (e.g. annual rainfall volume). Characterizing runoff during individual storm events from a large drainage area with a limited number of raingages, however, is a separate consideration. Significant variation in the measured runoff coefficient has been observed. Studies are now underway (22) to quantify a relationship between the raingage density, the type of storm patterns typical for an area, and the variation in the runoff coefficient. Preliminary results suggest that the variation in volumetric runoff coefficient can become substantial if the raingage density is less than one per square mile (22). When completed, the information gained from these studies will permit the variation of the runoff coefficient to be incorporated into the estimate of the variation of the runoff volume, ν_{vR} and the variation of the runoff flow, ν_q. Until then, the estimate of runoff variation may be based solely upon the variation of the measured rainfall parameters:

$$\nu_{vR} = \nu_v \tag{3-16}$$

$$\nu_q = \nu_i \tag{3-17}$$

Runoff flows and volumes have also been observed to be well represented by a gamma distribution. The cumulative density functions of Figure 3-11 may then be used to predict the fraction of storms and the expected number of times per year, month, or season that a given flow or volume is exceeded.

3.4.3.3 Determination of Loads

Runoff flows may be translated into stormwater loads by multiplying the runoff flows by the appropriate pollutant concentration, c (mg/l). If storm runoff flows and concentrations are independent, the mean runoff loading rate, (W_R, lbs/day), will simply equal the product of the mean concentration, ($\bar{c}$, mg/l), and the mean runoff flow, (Q_R, cfs).

$$W_R = 5.4 \cdot \bar{c}\ Q_R \tag{3-18}$$

It is best to begin by assuming $\bar{c}$ and Q_R are independent. If data collected for specific pollutants indicates they are not, the following refinement may be employed:

$$W_R = 5.4 \cdot \bar{c}Q_R\ (1 + v_c v_q \rho_{cq}) \tag{3-19}$$

where:

v_c = the variation of the pollutant concentration (between storms)

v_q = the variation of the runoff flow (between storms)

ρ_{cq} = the linear correlation coefficient between the pollutant concentration and the storm runoff flow (ranging from -1 to +1)

Positive correlation between the pollutant concentration and the storm runoff flow will yield a higher average loading rate, while negative correlation will yield a lower average loading rate. Note that the correlation between flow and concentration is not the first flush effect, which relates the concentration within storms to the time or volume since the beginning of the storm (to be dealt with in the section on storage/treatment in Chapter 6). The correlation dealt with here relates to storm event averages of the flow and concentration. Procedures for estimating pollutant concentrations in stormwater are presented in Section 3.4.2.2.

The variation of the runoff loading rate is due to the variation of the concentration and the flow. Assuming the flow and concentration are independent, the variation of the runoff loading rate, v_w, may be determined as follows:

$$v_w = v_q v_c \sqrt{1 + 1/v_q^2 + 1/v_c^2} \tag{3-20}$$

The calculation of the variation of the runoff loading rate, v_w, when flow and concentration are not independent has not yet been fully developed. Until the method (22) for determining the variation of the runoff loading rate, W_W, is developed for the case where flows and concentrations are not independent, the assumption that flows and concentrations are independent must be made, and Equation (3-20) used for a first estimate.

The actual cumulative density function for storm loading rates has not yet been determined. It is formed by the product of two gamma distributed random variables (c and q). As a first estimate, the loading rate is assumed to be gamma distributed as well, as is the case when a constant "typical" value is assigned to the runoff concentration. The cumulative density function of Figure 3-11 may again be used to predict the fraction of storms and the expected number of times per year, month, or season that a given storm loading rate is exceeded, as outlined in the section on rainfall characterization.

The average loading rate, W_R, is representative of stormwater loads during storm periods. The long term average mass discharge rate, W_O, is calculated by determining the total storm load during the year (pounds), and assuming that it occurs continuously (during both rain and non-rain periods). If the period of interest is a particular month or season, rather than the entire year, W_O may be calculated by determining the total storm load during the particular month or season, and by assuming that the storm load occurs continuously. W_O may also be calculated from the storm statistics for the year, month, or season of interest as follows:

$$W_O = W_R \, D/\Delta \qquad (3\text{-}21)$$

where:

D = average storm duration (hr)
Δ = average time between storms (hr)

W_O is the loading rate which is used to assess the cumulative long term stormwater effects and may be compared with the continuous municipal and industrial point source loadings to determine the relative magnitude of each source. As suggested in Section 3.4.3.1, at least five years of raingage data, either for the entire year, or during the particular month or season of interest, should be used to provide adequate confidence in W_0.

For pollutants which impact the receiving water in a transient fashion, such as coliforms or BOD_5, the long term loading rate, W_0, may not fully indicate the severity of the problem. For example, stormwater loads may contribute only a small part of the total yearly BOD_5 load entering a receiving water in a particular area, but the occurrance of this load only during storm periods may lead to violations of dissolved oxygen standards during or immediately following a number of rain events. It is for such cases that the actual mean loading rate during storms, W_R, and the variation, v_W, become the important indicators of stormwater loadings. The relative impact of long term and transient storm loads on receiving water quality is discussed in Chapter 5.

3.4.3.4 Modification of Loads by Existing System

Stormwater loads may be reduced by employing end of pipe control techniques, including interception and storage for eventual treatment (to be analyzed in detail in Chapter 6). Control measures may also include management practices, such as street sweeping. Where appropriate, the effect of these practices can be incorporated in the determination of the mean runoff concentration, $\bar{C}$, as discussed in Section 3.4.2.2.

If existing systems already contain some level of treatment or control, this must be incorporated in the determination of current stormwater loads. For urban areas with combined sewer systems, the interceptor will prevent a portion of the runoff from reaching receiving waters as storm overflows. A basis is available with the statistical methodology for analyzing the effect of combined sewer interceptors which have a capacity in excess of dry weather flows (DWF).

The conveyance system may be characterized by an excess interceptor capacity, Q_I, which is the available capacity in the interceptor for stormwater runoff. In a combined sewer system, Q_I is the total capacity minus the dry weather flow (determined by regulator operation). The fraction of the long term runoff load, f_I, which is captured by an interceptor with excess capacity, Q_I, has been calculated and is shown in Figure 3-12. The performance is a function of the ratio of the excess capacity to the mean runoff flow, Q_R, and the variation of the runoff flow, v_R. Note that the greater the variation in runoff flow, the more poorly the interceptor will perform on average. The reduction of the long term runoff load corresponds to a reduction in the mean runoff loading rate, W_R, for storm events. The fraction not captured is $f_I = \bar{W}/W_R$ (where $\bar{W}$ is the load bypassed or overflowed).

Conveyance systems also provide a degree of in-system storage, V_E, both in the pipe themselves and due to the layout of diversion structures. The storage capacity effectively retains runoff until the storm subsides, when the stored stormwater may then be fed to the treatment system or directly to the stream. The long term performance of a storage device is a function of the ratio of the effective storage capacity to the mean runoff volume, V_R, and the variation of the runoff volume, v_{VR}. Note that the volume utilized by the dry weather flow should be subtracted from the total internal storage to determine the effective storage capacity. The long term performance curves are shown in Figure 3-13. The fraction of the load not captured is $f_V = \bar{W}/W_R$. These curves were drawn assuming there is no first flush effect. When a first flush effect does exist, a disproportionately high fraction of the runoff load will be captured by the storage device. The improvement in long term storage device performance due to the first flush effect is depicted in Figure 3-14. When the first flush exists, Figure 3-14 may be used to redraw the performance curve obtained from Figure 3-13, with the corresponding new values of f_V. The fraction of the load not captured by the combined effect of interception and storage, f_{IV}, may be approximated by the product of the individual fractions not captured: $f_{IV} = f_I f_V$.

Assuming that the load captured by the conveyance system receives treatment such that there is a fractional removal, r, the resultant mean runoff loading rate, W_R^*, will be:

$$W_R^* = f_{IV} W_R + (1-f_{IV})\, W_R (1-r) \qquad (3\text{-}22)$$

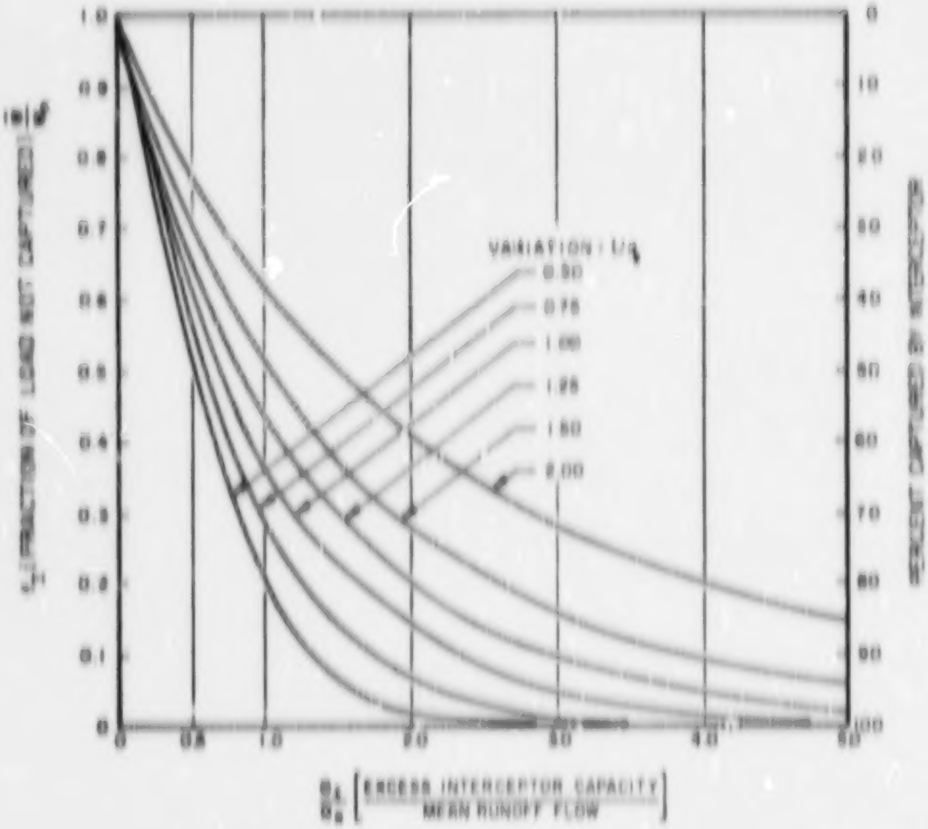


FIGURE 3-12
DETERMINATION OF LONG TERM INTERCEPTOR PERFORMANCE

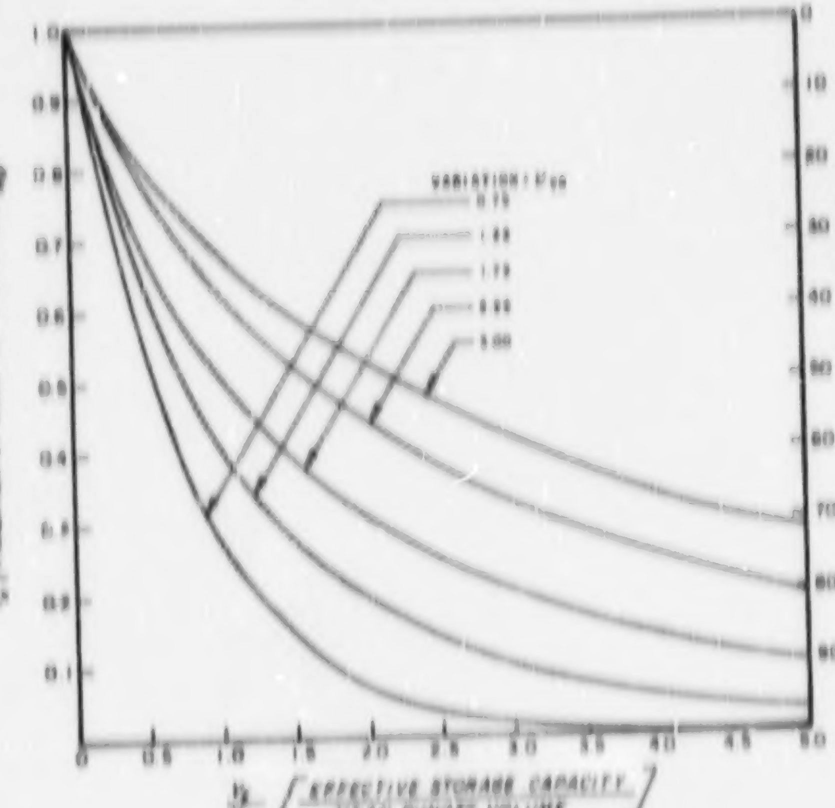


FIGURE 3-13
DETERMINATION OF LONG TERM STORAGE DEVICE PERFORMANCE

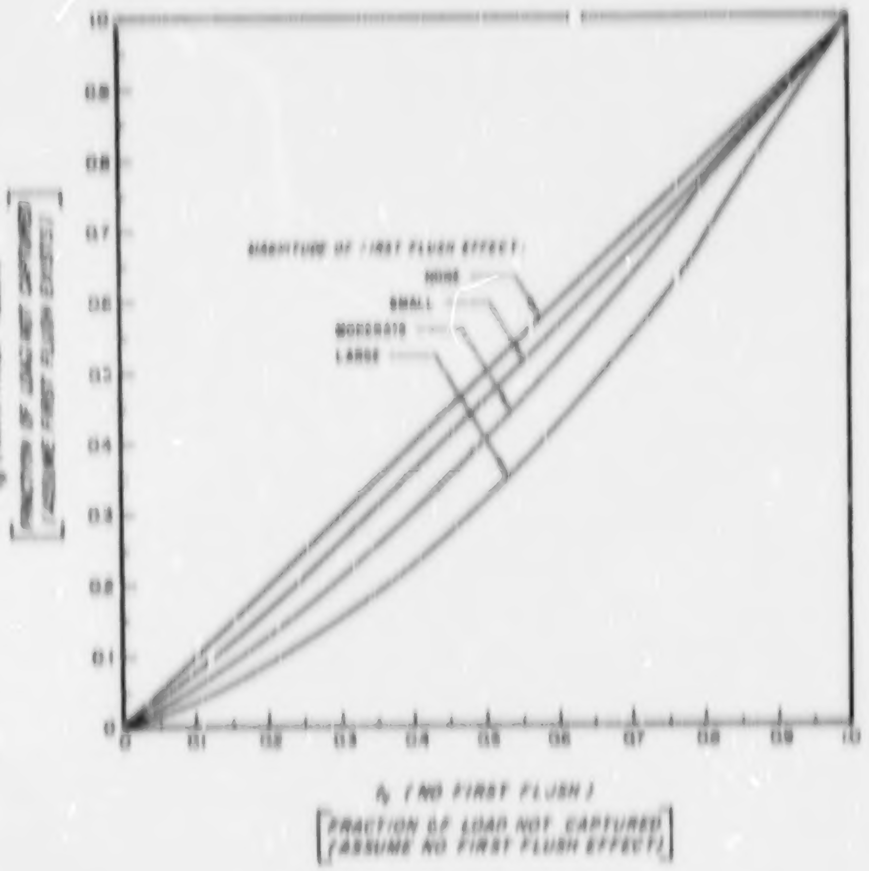


FIGURE 3-14
IMPROVEMENT IN LONG TERM STORAGE DEVICE PERFOMANCE
DUE TO FIRST FLUSH EFFECT

In a combined sewer system, r would represent the treatment received at the municipal treatment plant. The curves relating the impact of interception and storage on the variation of the runoff load are currently being developed (22).

3.4.3.5 Receiving Water Quality Impact Analysis

Once the stormwater loads have been determined, they are applied to the receiving water. The statistical nature of the resulting loads, together with the receiving water characteristics, determine the statistical properties of pollutant concentrations in the receiving water. Factors such as advection, dispersion, reaction, and background concentrations in the receiving water will determine the resulting water quality impact. Statistical analyses may be necessary for both transient and long term concentrations. Methods for performing these analyses will be presented in Chapter 5. The final output of the methodology is the predicted frequency with which relevent water quality standards and guidelines are violated.

3.4.3.6 Example Application of the Statistical Method

To illustrate the use of the statistical method, an example will be presented for a hypothetical drainage area, using rainfall records from the City of Denver, Colorado.

Statistical Rainfall Characterization

Twenty-five years (1949 through 1973) of hourly rainfall data for U.S. Weather Bureau Station 052220 were analyzed. The resulting storm statistics were calculated for each month and are shown in Figure 3-15. Seasonal patterns are evident in the data, with shorter, more frequent and more intense storms occurring in the summer. Assuming that critical water quality conditions occur during the summer, from June through September, the relevent storm characteristics should be taken from this period. These are summarized below.

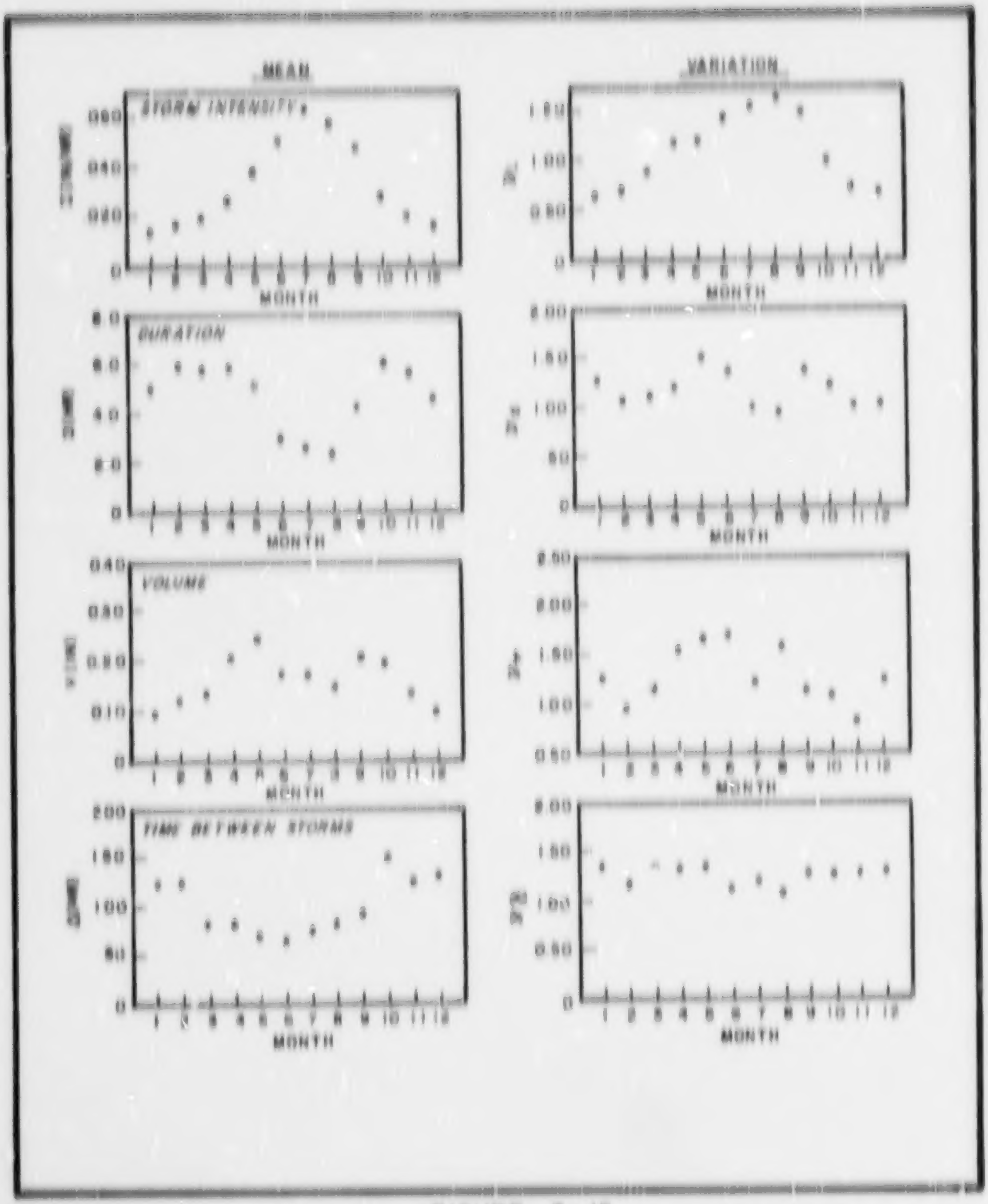


FIGURE 3-15
MONTHLY STATISTICAL RAINFALL CHARACTERIZATION
DENVER, COLORADO
STATION 052220

APPROXIMATE SUMMER STORM CHARACTERISTICS FOR DENVER
(JUNE THROUGH SEPTEMBER)

Characteristics	Mean	Variation
Storm Intensity	$I = 0.055$ in/hr	$\nu_i = 1.55$
Duration	$D = 3.0$ hr	$\nu_d = 1.15$
Volume	$V = 0.18$ in	$\nu_v = 1.90$
Time Between Storms	$\Delta = 80$ hr	$\nu_\delta = 1.15$

Determination of Runoff

The hypothetical drainage area is estimated as 1875 acres with an imperviousness of a little over 30 percent. Assume that 70 percent of the area is served by separate sewers or natural conveyance, and 30 percent is served by combined sewers. Given this assumption, the separate or unsewered area is 1310 acres, and the combined sewer area is 565 acres. In the example calculation it is assumed that the percent imperviousness is the same in both subareas. The runoff coefficient, C_V, for both subareas, is estimated from Figure 3-8, to be 0.35. One should note, however, that the population density in combined sewered areas is generally greater than that of separate sewered areas. Thus the percent imperviousness as shown in Equation 3.2 and consequently the runoff coefficient is usually higher in combined sewered areas.

The mean runoff flow and volume during summer months is calculated from the approximate summer storm characteristics, the runoff coefficient, and the drainage areas.

Separate or Unsewered Area

$$
\begin{aligned}
V_R &= 3630 \cdot C_V V A \\
&= 3630(\text{ft}^3/\text{acre-in}) \cdot (0.35) \cdot (0.18\ \text{in}) \cdot (1310\ \text{acre}) \\
&= 3 \times 10^5\ \text{ft}^3 \\
Q_R &= C_V I A \\
&= (0.35) \cdot (0.055\ \text{in/hr}) \cdot (1310\ \text{acre}) \cdot (1\ \text{cfs}/(\text{acre-in/hr})) \\
&= 25\ \text{cfs}
\end{aligned}
$$

Combined Sewer Area

$V_R = 3630\ (\mathrm{ft}^3/\mathrm{acre\text{-}in}) \cdot (0.35) \cdot (0.18\ \mathrm{in}) \cdot (565\ \mathrm{acre})$

$\quad = 1.3 \times 10^5\ \mathrm{ft}^3$

$Q_R = (0.35) \cdot (0.055\ \mathrm{in/hr}) \cdot (565\ \mathrm{acre}) \cdot (1\ \mathrm{cfs}/(\mathrm{acre\text{-}in/hr}))$

$\quad = 11\ \mathrm{cfs}$

The variation of the runoff volume and flow in both subareas may be estimated from the variations calculated for the corresponding rainfall values:

$\nu_{VR} = \nu_V = 1.00$

$\nu_q = \nu_i = 1.55$

Determination of Loads

For this example, BOD_5 will be used as the variable of interest. From Table 3-3, the BOD_5 concentration of the runoff from the separate and unsewered area, $\bar{c}_s$, is estimated to be 27 mg/l, and the BOD_5 concentration of the runoff from the combined sewer area, $\bar{c}_c$, is estimated to be 108 mg/l. The resulting loading rate, W_R, during summer storms is calculated as follows:

Separate or Unsewered Area

$W_R = 5.4 \cdot \bar{c}_s Q_R$

$\quad = (5.4\ \mathrm{lb/day/cfs\text{-}mg/l}) \cdot (27\ \mathrm{mg/l}) \cdot (25\ \mathrm{cfs})$

$\quad = 3600\ \mathrm{lb/day}\ BOD_5$

Combined Sewer Area

$W_R = 5.4 \cdot \bar{c}_c Q_R$

$\quad = (5.4\ \mathrm{lb/day/cfs\text{-}mg/l}) \cdot (108\ \mathrm{mg/l}) \cdot (11\ \mathrm{cfs})$

$\quad = 6400\ \mathrm{lb/day}\ BOD_5$

The variation of the BOD_5 loading rate for each subarea, ν_W, is estimated using Equation (3-20). The variation of the flows, ν_q, has been estimated as 1.55, and the variation of the BOD_5 concentration, ν_c, may be conservatively estimated as 1.00, because local data is not available. The calculation of ν_W follows:

$$\nu_W = \nu_q \nu_c \sqrt{1 + \frac{1}{\nu_c^2} + \frac{1}{\nu_q^2}}$$

$$= (1.55) \cdot (1.00) \sqrt{1 + \frac{1}{(1.00)^2} + \frac{1}{(1.55)^2}}$$

$$= 2.41$$

The long term summer loading rate, including the non storm periods, will be:

Separate or Unsewered Area

$W_0 = W_B {}^D/_{\Delta}$ = (3600 lb/day) . (3.0 hr/80.0 hr) = 135 lb/day BOD_5

Combined Sewer Area

W_0 = (6400 lb/day) . (3.0 hr/80.0 hr) = 240 lb/day BOD_5

The total average loading rate from both the separate or unsewered and combined sewer areas may be calculated by adding the loads from each:

Total Drainage Area (Hypothetical)

W_B = (3600 + 6400) = 10,000 lb/day BOD_5

W_0 = (135 + 240) = 375 lb/day BOD_5

The simplified assumption that storm loads are gamma distributed may now be used to estimate the frequency of occurrence of different loading rates from the total drainage area. Given that $\nu_W = 2.41$, Figure 3-11(b) indicates the cumulative density function for storm loads in multiples of the average load, W_B = 10,000 lb/day BOD_5. The average number of storms per summer will be:

$$\text{Average number of storms} = \frac{\text{Length of Period}}{\Delta}$$

$$= \frac{122 \text{ day (June-Sept.)} \times (24 \text{ hr/day})}{80 \text{ hr}}$$

$$= 36.6$$

The number of storms per summer exceeding a given average loading rate is then the fraction exceeding that rate times the average number of storms. The calculations for various loading rates are summarized below:

FREQUENCY OF STORM LOADS FOR HYPOTHETICAL DRAINAGE AREA

W (lb/day BOD_5)	W/W_R	Percent less than or Equal to W	Fraction Greater than W	Number of Storms Per Summer Greater than W
10,000	1.0	79	0.21	7.7
20,000	2.0	86	0.14	5.1
30,000	3.0	89	0.11	4.0
40,000	4.0	92.5	0.075	2.7
50,000	5.0	94.5	0.055	2.0

W_R = Avg. Summer Runoff Load = 10,000 lb/day BOD_5

Modification of Loads By Existing System

The stormwater loads for the hypothetical drainage area have been calculated by assuming 70 percent of the area is served by separate or unsewered conveyances, and 30 percent of the area is served by combined sewers. Existing separate sewer systems generally convey runoff loads to the receiving water without modification. The combined sewer load, however, will be modified by the interceptor system. Assume that the combined sewer area interceptors have an excess capacity of 11 cfs, equal to the mean runoff flow (Q_I/Q_R = 1.0), and an internal storage of 0.65×10^5 ft^3, or one half the mean runoff volume (V_E/V_R = 0.50). For Q_I/Q_R of 1.0, and v_q of 1.55, Figure 3-12 indicates the fraction not captured by the interceptor, f_I is 0.53. For V_E/V_R of 0.50, v_{VR} of 1.00, and a moderate first flush effect, Figure 3-13 and 3-14 are used to determine the fraction not captured by storage, f_V of 0.68. Therefore, the fraction of runoff not captured due to both interception and storage, f_{IV} is (0.53)(0.68) or 0.36. Assuming the captured runoff is treated with forty percent removal (r = 0.40), the modified average summer storm load, W_R', from the combined sewer area is:

Combined Sewer Area

$$W_R' = f_{IV}W_R + (1-f_{IV})W_R(1-r)$$

$$= (0.36)\ (6400) + (0.64)\ (6400)\ (0.60)$$

$$= 4760 \text{ lb/day } BOD_5$$

with a long term modified summer mass discharge rate, W_U':

$$W_U' = 180 \text{ lb/day } BOD_5$$

Therefore the total modified storm load from the drainage area, including both the spearate or unsewered area, and the combined sewer area is:

Total Drainage Area

$$W_R' = (3600 + 4760) = 8360 \text{ lb/day } BOD_5$$

$$W_U' = (135 + 180) = 315 \text{ lb/day } BOD_5$$

As the purpose of this chapter is to demonstrate methods for stormwater load estimation, example receiving water calculations will not be shown here, but will appear in Chapter 5.

3.4.4 A Simulation Method for the Assessment of Storm Loads

In addition to the statistical method, storm loads in urban areas may also be estimated by the use of simulation techniques. Simulators can be particularly useful in the examination of storm loads, the problems they cause, and their control measures, because of the detailed representation of the sequence of individual events, both in space and time, which they provide.

A review of Appendix A will indicate that available simulators represent a wide range of sophistication and level of detail. Most operate from an input of hourly rainfall data, and, based on physical characteristics and properties assigned to the drainage area, they calculate the loads generated on the same time scale as the rainfall input. The simulators which can be utilized to the best advantage in the assessment stage in 208 planning, are those which at the sacrifice of detail for individual storm events, are able to process relatively long periods of rainfall records and thus simulate a broad range of individual events.

A simulator which is considered to be particularly suitable for use in assessment studies is described below. The description is intended to provide information on the basic methodology employed by simulators in general, and to illustrate how a simulator can be utilized in the estimation of urban stormwater loads. The model which will be discussed is a simplified stormwater management simulator, developed by Metcalf and Eddy and used during a stormwater assessment study for Rochester, New York (29). It was developed as a screening technique for the planning and preliminary sizing of control facilities, and is more suitable for use in assessment studies than the more complex simulators for which it was substituted. The simulator can be used for the estimation of loads from combined, separate or unsewered systems.

Use of the simplified stormwater simulator for estimating storm loads includes the following tasks:

1. Rainfall Characterization
2. Data Preparation
3. Storage - Treatment Balance
4. Overflow-Quality Assessment

These are a series of interrelated tasks that can be performed either individually or together, and are composed of small computer programs and hand computations. The storage-treatment balance is the component which uses the computer simulator. The simulator generates a continuous record of overflows from a stormwater collection system by reproducing the drainage area characteristics and calculating responses to rainfall.

The other tasks listed are either required as support for the simulator (data preparation and overflow-quality assessment) or provide additional input in the overall stormwater assessment study (rainfall characterization). It will become apparent in discussing the tasks how each fits into the assessment.

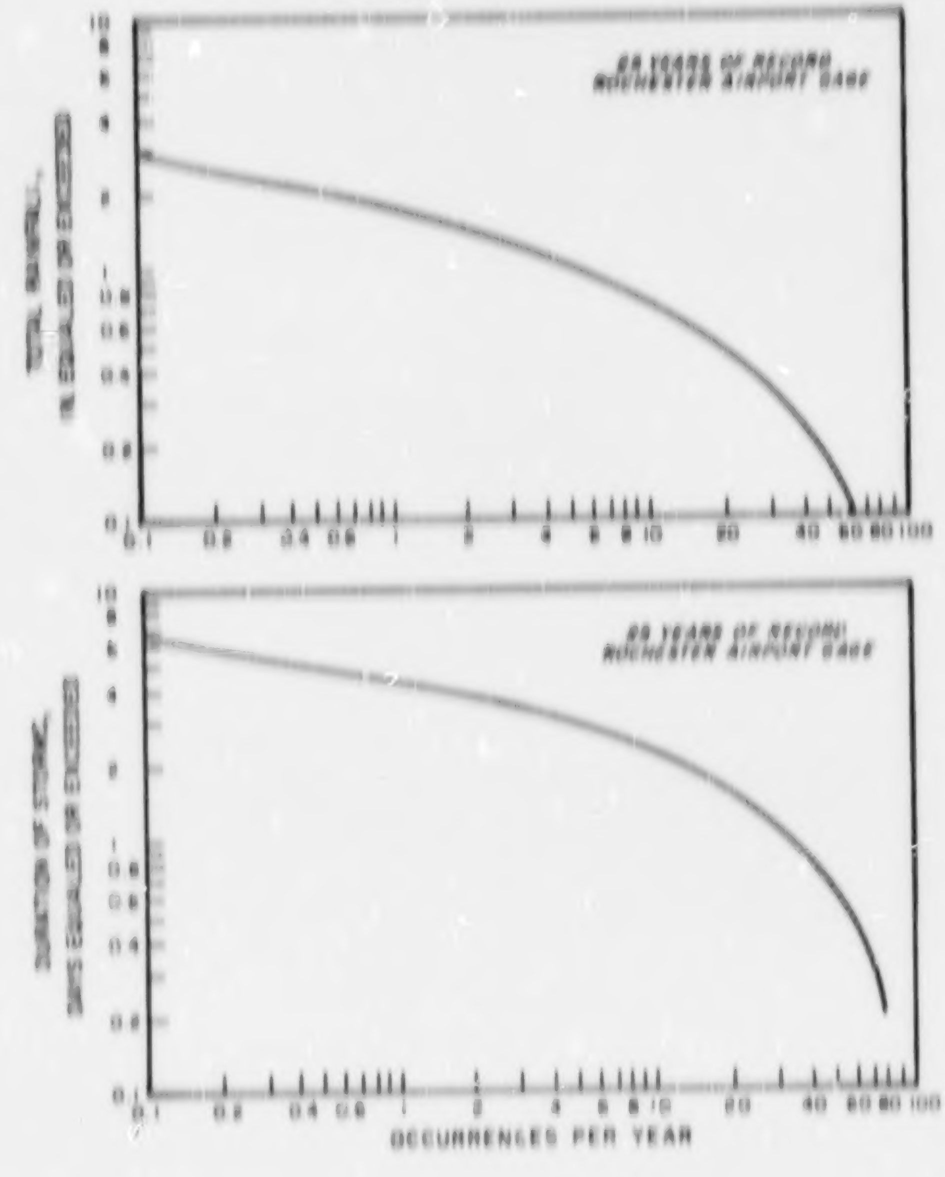
Rainfall characterization is a part of the approach incorporated into this simplified simulator to provide insight into the characteristics of rainfall and therefore runoff, occurring in an area. This characterization is similar to that employed in the statistical method previously described in that it characterizes the relative frequency of rain events or the properties of rain events, e.g. duration, total rainfall per storm, maximum intensity, etc. Examples of frequency curves presented in Figure 3-16 indicate the number of occurrences per year for storm volume and storm duration. Procedures for generating these characteristics from rainfall records are provided in the referenced report (20).

The methodology provided in this report will give information on the following items:

1. The total number of storms.
2. The number of storms having a total volume of less than 0.1 inch (approximate depression storage value).
3. The number of storms having durations greater than 24 hours.
4. The average number of days between storms.

The characteristics defined by this rainfall analysis are not used directly in the simulator, but as background information to aid in the evaluation and interpretation of results.

Data preparation is an important step in the modeling process. In addition to rainfall data, information on drainage area and collection system characteristics must be secured in order to provide the required input for the operation of the simplified simulator.



REFERENCE [illegible]

FIGURE 3-16
FREQUENCY OF STORM OCCURRENCES

Simplified simulator operation is illustrated conceptually by Figure 3-17. In the program, rainfall is converted into runoff, by using a K factor which is a volumetric runoff coefficient similar to the C_v that is used in the statistical method presented earlier. The runoff is stored in a specific storage volume, which represents the volumetric capacity of the storm and combined sewer system. Runoff which enters the system is removed by a specific "treatment rate" which represents the hydraulic capacity of the interceptor downstream of the overflow point. For combined sewers, both the storage volume and the interceptor capacity ("treatment rate") used in the simulator are previously calculated "net" values, which account for volume and flow capacity utilized by dry weather sanitary sewage flow (DWF). The schematic thus illustrates a combined sewer system. Separate storm sewer systems or natural conveyances in unsewered areas would be accomodated simply by equating DWF to zero, and the interceptor capacity to zero. Thus, the only flow in the system is storm runoff, and all of it "overflows".

When runoff exceeds the storage capacity with a continuous flow greater than the "treatment flow rate" during the time interval analyzed, an overflow occurs. The simulator can function on either a daily or hourly time step. A daily time step is suggested for analysis initially in order to make analysis of an entire period of record (often 20 years or more) practical. Examination of this output is used to identify critical periods for further examination. For specific periods of interest, including critical storms, the analysis may be performed on the hourly time step.

The simplified simulator calculates runoff from a drainage area and the net amount which enters the receiving water through overflows from the collection system. When suitable pollutant concentations are assigned to the runoff or overflow volumes, storm generated pollutant loads are calculated as the product of volume and concentration.

The critical elements which determine the accuracy of the waste loads calculated by the simulator are the relationships established for:

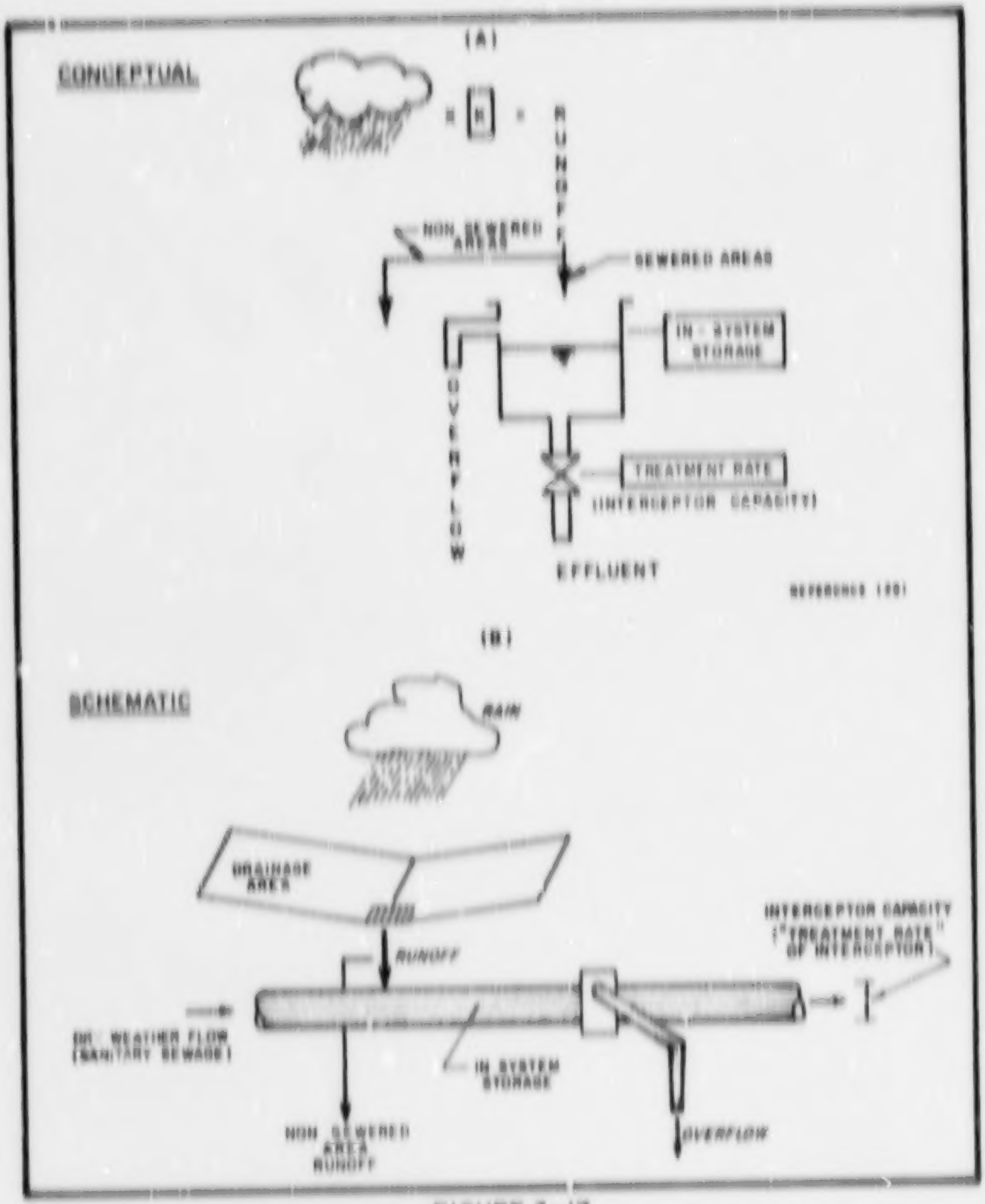


FIGURE 3-17
CONCEPT OF STORAGE-TREATMENT PROGRAM

1. Defining the component of rainfall which will leave the drainage area as runoff. This is the volumetric runoff coefficient, C_v, (or K, depending on the reference used).
2. Defining the pollutant concentrations associated with the runoff.

The output from the simulator is a record of the time and volume of runoff and overflows, and the waste loads associated with them, together with a summation of these parameters. The summation is terminated at the end of each year for the daily analysis, and at the end of each month for the hourly analysis.

The simulator operates on actual rainfall records, and therefore it internally accounts for the synergistic effect of storms coming close together with overlapping demands on storage capacities. If the rainfall record covers many years, then the runoff, overflow volumes and durations can be filed and ranked, and a statistically significant frequency of occurence curves can be generated.

3.4.4.1 Example Application of the Simplified Simulator

The simulator can be applied, utilizing a range of levels of spatial detail. In its simplest form, it would operate on a single aggregated drainage area in the same manner the statistical method was applied in the previous example. The addition of spatial detail may be employed when appropriate, while still utilizing the basic rain-runoff-quality calculations which are employed at the simplest level.

For the simplest case, use of the simulator would involve the following steps:

1. Secure rainfall records. They may be analyzed to determine the statistical properties for aid in evaluating simulator output. Hourly rainfall data is used in the simulator.
2. Characterize the Drainage Area

   a. Determine total area, area served by combined sewers, and separate and unsewered area.

b. Determine percent impervious area, using guidelines or estimating relationships previously presented.

c. Estimate runoff coefficient (called K factor in this reference), using either available data or basing estimate on imperviousness.

d. Estimate or measure average dry weather sewage flow.

3. Estimate or determine internal storage in sewer system, and a "typical" interceptor capacity for combined sewers which is representative of sewers in the area. Separate storm sewers or natural conveyances would have both internal storage and "interceptor capacity" set at zero, since all storm runoff reaching such systems will "overflow". For combined sewers, net interceptor capcity is established as the difference between the hydraulic capacity of the sewer line and that part of the capacity utilized by dry weather flow.

To operate the simulator, each of the above parameters which are characteristic of the study area are incorporated into the program as constants. A record of hourly rainfall data is then read as program input. Output will consist of a tabulation of the runoff and overflow volumes to the receiving water for the period of record analysed.

This tabulation may then be summarized, averaged or analyzed statistically to characterize the volumetric storm overflows.

Storm loads may be determined by assigning a pollutant concentration to the simulated volumes and calculating a load. In the absence of local data, relationships previously presented may be employed for estimates of typical concentrations.

Additional insight into the use of the simulator at any level of spatial detail will be provided by examination of the subsequent example application.

The example presented below illustrates a more detailed application of the simplified simulator. It describes the estimation of storm runoff loads from the Rochester, N.Y. urban area (20), which has both separate and combined sewer systems.

System schematic diagrams which show the overflows, drainage areas associated with the overflows and the pertinent interceptor capacities for the combined sewers are required to identify the characteristics of the sewer system and its existing overflow points. An essential first step in developing these data is to acquire the best and most recent sewer and storm drainage maps for the region under investigation.

Overflows are defined as any point on the collection and interceptor system specifically designed to permit excess flows to bypass the routing to the treatment plant. Some of the important characteristics of the overflows which should be identified in the system schematic are:

1. Location of the overflows on the interceptor system
2. The hydraulic capacity of the overflows and/or regulating structures that control the overflows
3. The capacity of any restrictions within the interceptor system that restrict flow to the overflow
4. The drainage area served by the overflow point.

Drainage areas or subareas are defined by delineating the sewered area that is tributary to a particular overflow structure (one overflow for each subarea). These drainage subareas subdivide the entire sewered area. The signficant characteristics of each drainage subarea are:

1. The total surface area
2. Percent of the subarea that is impervious
3. Percent distribution of the industrial, commercial, and residential (single-family and multifamily) and other significant land uses
4. Average slope of the ground
5. Average dry-weather flow.

The interceptor system described in the schematic should include the following information:

1. The components that connect each subarea to the treatment plant
2. The maximum capacity of these components

3. The capacity of components that are particularly restrictive in the system near an overflow
4. The available in-system storage.

The maximum capacities of the interceptor system are often calculated using Manning's equation assuming unsurcharged open channel flow. If the system can surcharge, significantly higher flow rates can occur and appropriate values for maximum interceptor capacity should be calculated.

In-system storage should be identified where it provides significant volumes in trunk lines or in interceptors. The effort required to define both existing and any unrealized potential for in-system storage is worthwhile, since in some cases storage volume in such existing lines may be increased dramatically by low cost modifications (e.g. weirs, dams), and provide a cost effective control technique.

An example of a system schematic prepared for the Rochester, New York study is shown by Figures 3-18, 3-19 and 3-20. These figures illustrate the sequential development and consolidation of pertinent data utilized in the operation of the simplified simulator.

On a map of the urban area, all significant overflows are located. Then, using sewer and storm drainage system maps, the drainage sub-catchment area which contributes flow to the system at each overflow point is delineated (Figure 3-18).

A schematic of the collection system is then prepared (Figure 3-19) which indicates clearly the routing, interconnections and other features of the system. The location of the input to the system from each of the sub-areas is shown. The hydraulic capacity of the lines between each of the sub-area inflow points and each overflow point are determined and recorded.

Figure 3-20 represents a final condensation of the salient features of the collection-overflow system. It summarizes and illustrates the physical and spatial characteristics of the drainage area which will be structured into the simplified simulator. It defines the routing of the

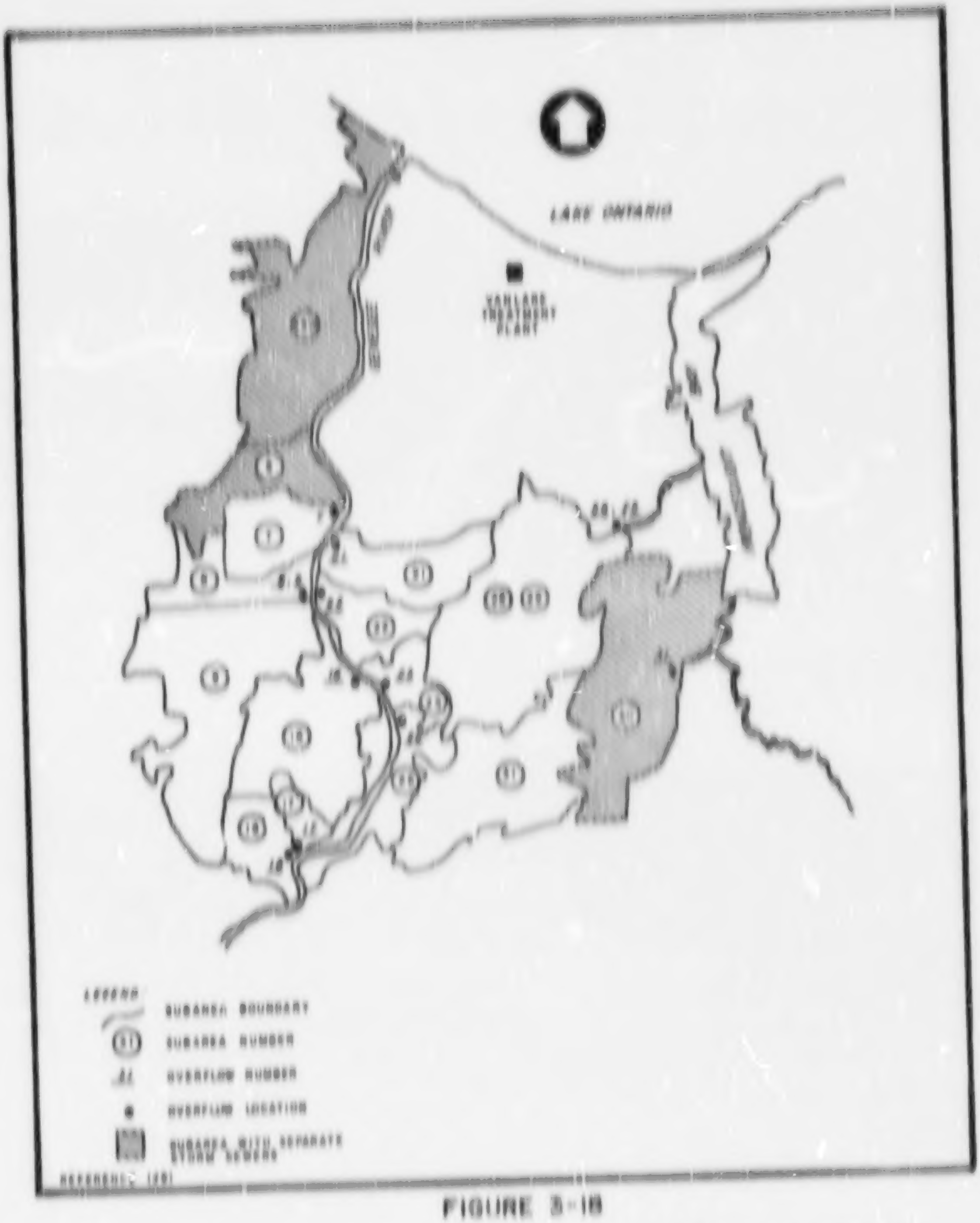


FIGURE 3-18

ROCHESTER SUB-DRAINAGE AREA AND OVERFLOW LOCATIONS

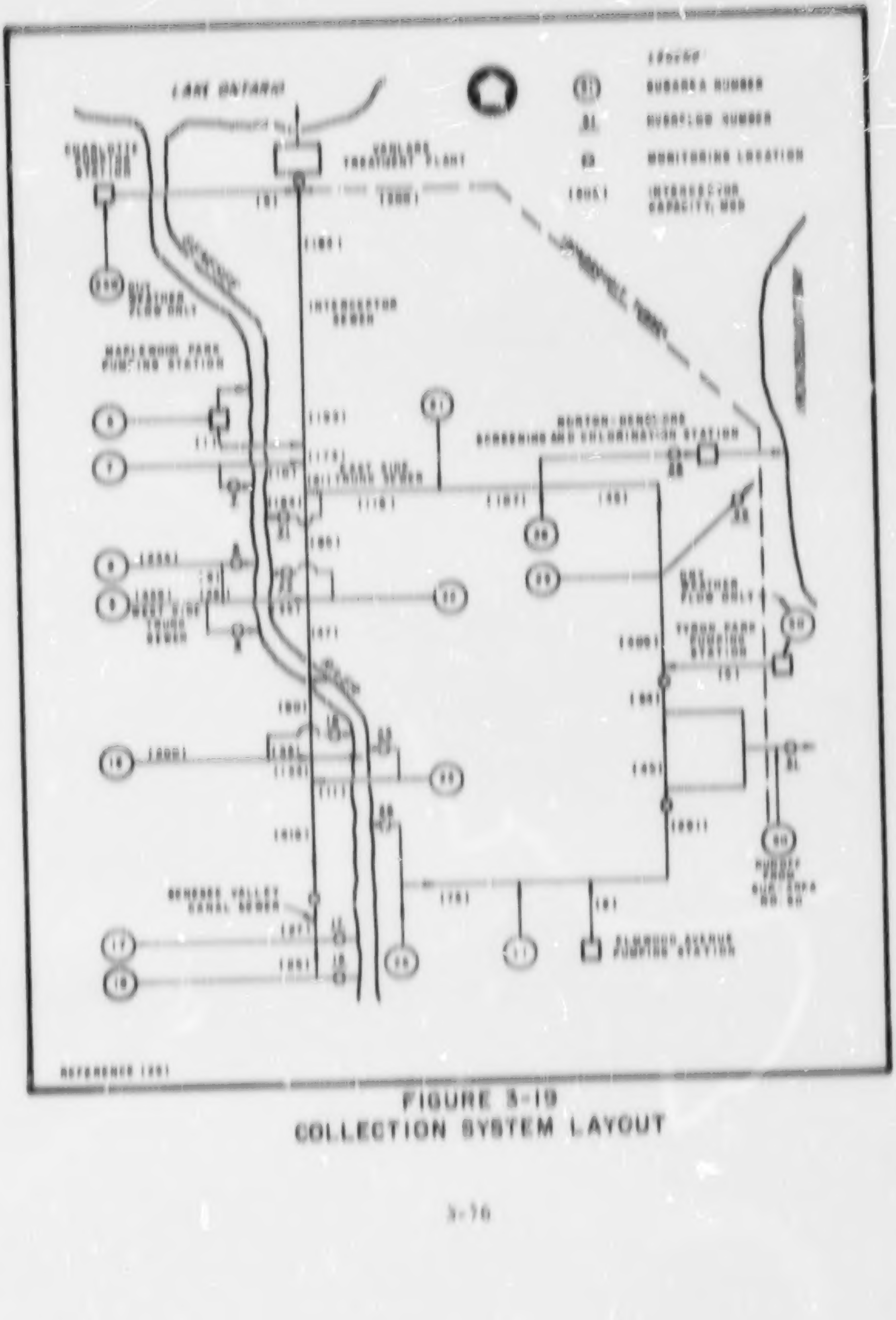
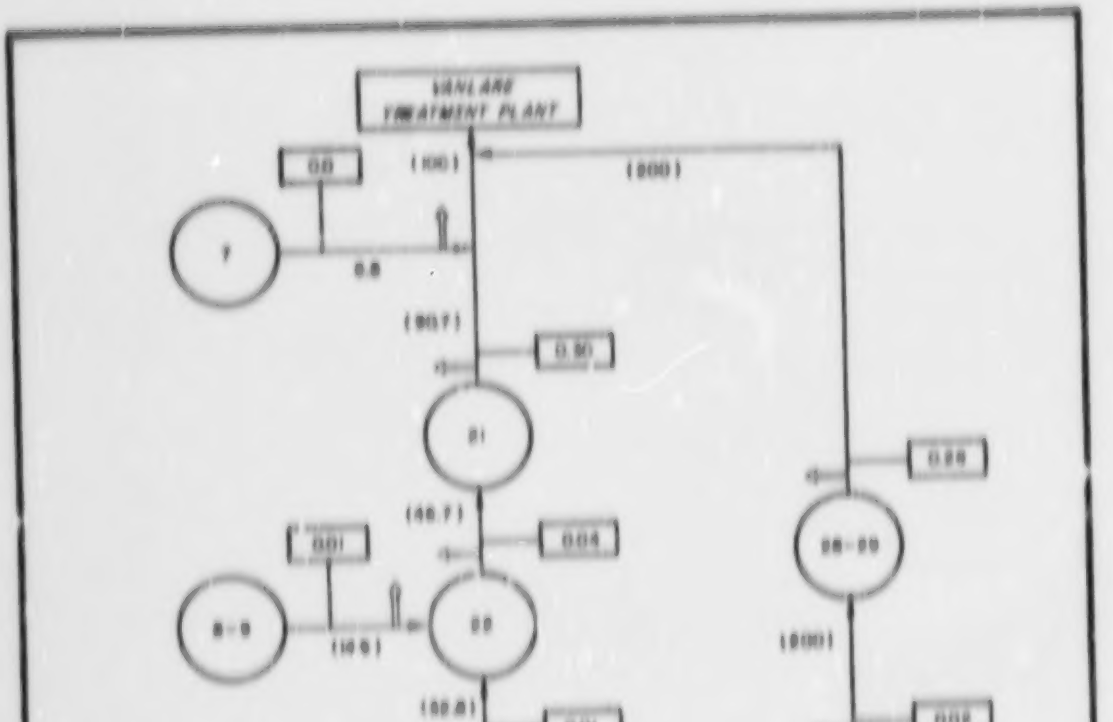


FIGURE 3-19
COLLECTION SYSTEM LAYOUT



REFERENCE (25)

FIGURE 3-20
SUMMARY OF COLLECTION SYSTEM

storm flows and loads which will be generated for each of the indicated sub-areas by the load generating methodology employed in the simulator.

Storm loads are generated by the simplified simulator on the basis of rainfall and the characteristics of each of the sub-catchments. The significant features of the drainage area are determined, and summarized as illustrated in Table 3-7. Procedures for developing land use data bases are described in Appendix C. For the Rochester, New York study illustrated by this example, aerial photographs supported by field observations were used to define the distribution of the total area into the various land use categories. Area determinations were made by planimeter measurements from maps and photographs. Slopes were determined by a field survey, and the imperviousness was estimated on the basis of aerial photographs supported by field observations. The average dry weather sewage flow (DWF) in the combined sewers was estimated using the contributing population for each sub-area factored by a per-capita rate of flow.

Table 3-8 illustrates the procedure used to calculate the available wet weather capacity of the interceptor system. This is determined for each limiting segment downstream of an overflow point, as the difference between (a) hydraulic capacity of the interceptor which is based on diamrter and slope, and (b) the cumulative dry weather sewage flow in the line at that point.

Figure 3-21 illustrates the results of a statistical analysis performed on the simulator output for long term rainfall records for the Rochester, New York example. Both runoff volume, and overflow from the combined sewer collection system were analyzed and the plot indicates graphically the estimated amount of total storm runoff retained by the existing system of interceptors. As a long term average, the data may be interpreted to indicate that approximately 70 percent of runoff is intercepted and contained by the existing system. For the larger storm events, which occur less frequently, this retention efficiency can be expected to be less than 50 percent. Waste loads would be estimated by assigning an appropriate concentration, obtained from Section 3.4.7.2, to these volumes.

TABLE 3-7

EXAMPLE OF DRAINAGE SUBAREA CHARACTERISTICS

Sub-area No.	Total area, acres	Land Use, % Residential Single-family	 Multi-family	 Commer-cial	 Indus-trial	 Open	Average slope, ft/ft	Imper-vious Area, %	DWF (maximum avg), MGD
6[a]	1,277	19.3	1.3	1.9	65.6	11.8	0.0074	55.0	7.06
7	715	85.9	1.0	7.3	0.2	5.5	0.0118	50.0	3.21
8	984	34.5	2.2	47.0	3.2	13.2	0.0066	45.0	6.36
9	2,665	52.5	0	4.1	37.1	6.4	0.0060	50.0	14.00
16	826	50.0	9.4	33.8	1.1	5.7	0.0070	55.0	5.78
17	255	85.8	3.8	2.1	0	10.2	0.0067	40.0	1.55
18	541	95.7	0.6	3.8	0	2.2	0.0075	40.0	2.60
21	621	79.4	0	9.0	6.8	4.9	0.0065	35.0	4.60
22	569	59.6	25.5	6.7	4.9	3.3	0.0070	50.0	3.41
25	548	30.0	9.9	44.9	5.0	10.2	0.0080	80.0	4.50
25a[a]	1,390	50.0	10.0	24.0	10.0	10.0	0.0150	35.0	6.01
26	554	30.0	9.9	44.9	[illegible]	9.9	0.0100	65.0	5.91
28	778	65.0	10.0	10.0	4.9	10.0	0.0100	50.0	4.36
29	1,430	65.0	10.0	10.0	5.0	10.0	0.0100	55.0	7.86
31	1,382	50.0	10.0	20.0	15.0	5.0	0.0100	47.0	10.13
50[a]	1,725	65.0	20.0	5.0	5.0	5.0	0.0150	40.0	11.90

[a] Serviced by separate storm sewers

Reference (29)

TABLE 3-8

EXAMPLE OF CALCULATION OF WET-WEATHER FLOW CAPACITY, MGD

Subarea Number	DWF[a] maximum average (1)	Sum of DWF (2)	Maximum interceptor capacity (3)	Available wet-weather capacity (4)
West Side System				
17 and 18	3.9	3.9	416	412.1
25	4.5	8.4	123	114.6
16	5.8	14.2	47	32.8
8 and 9	20.4	34.6	35	14.6[b]
12	3.4	38.0	84.7	46.7
21	44.7[c]	82.7	173.4	90.7
7	3.2	85.9	10.0	6.8[b]
6	7.0	92.9	184	100.0
East Side System				
26	5.9	5.9	....	....
31	22.0	27.9[d]	200	200
28 and 29	12.2	40.1[d]	200	200

[a] DWF = (Average) Dry Weather Flow

[b] The limiting segment is not on the main interceptor

[c] Of this amount, 4.6 MGD is from Subarea 21; 40.1 MGD is from the East Side trunk sewer

[d] The equivalent of DWF is carried by the east side trunk sewer

Reference (29)

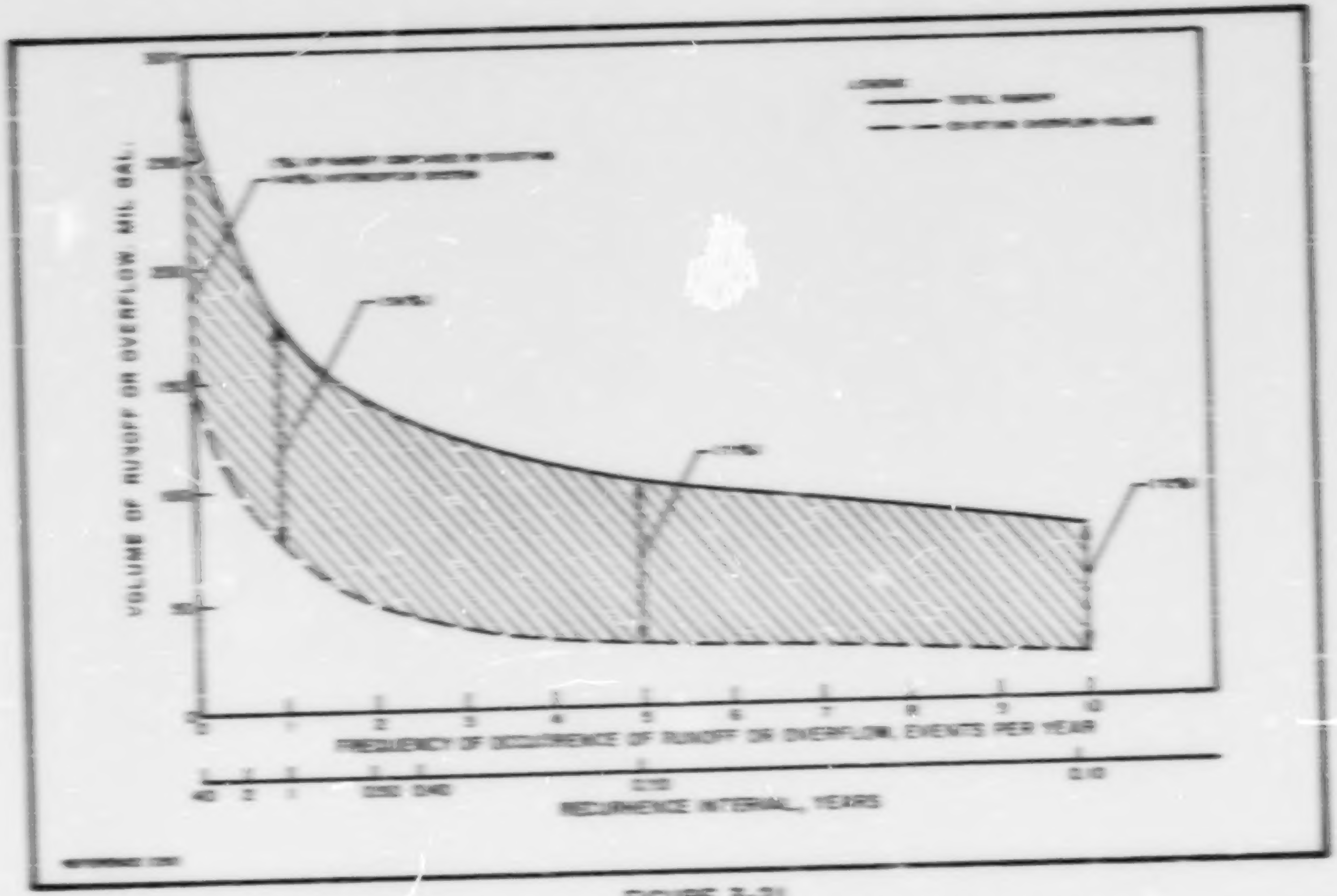


FIGURE 3-21

FREQUENCY OF OCCURRENCE OF RUNOFF AND OVERFLOW

3.4.5 Alternate Source Generation and Transport Prediction Methods

Each of the methods to estimate stormwater loads, discussed previously in this chapter, characterize the concentration of various pollutants in stormwater runoff. Estimates of concentration are empirical and are based on one or more of the following:

1. Collection system type (combined or separate)
2. Land use
3. Rainfall characterisitcs (intensity, duration, interval between storms).

Appropriate concentrations are assigned to runoff or overflow volumes for the calculation of storm loads. These stormwater load characterizations estimate "end-of-pipe" loads which will discharge either to receiving waters or to control devices. Chapter 5 describes procedures for estimating water quality impacts in receiving waters for the storm loads. Chapter 6 describes procedures for assessing the effect of various control measures on these loads. The characterization of end-of-pipe storm loads, developed by the methodologies described in this chapter, provide information in a form which can be utilized directly in these subsequent analyses.

Other techniques for estimating storm loads have been developed and are employed in some of the methodologies presented in Appendix A. Instead of utilizing empirically determined values or relationships for pollutant concentrations, descriptive models of the mechanisms by which pollutant loads are generated on land surfaces and transported to receiving waters are formulated and incorporated into the load estimating procedure.

Figure 3-22 illustrates the characterization of a drainage basin for use with models which employ source generation and transport. A drainage area is composed of pervious and impervious surfaces, and a distinct mechanism of pollutant generation and transport by storms is used for each land surface type. Sediment and sediment-like material is used as the indicator for pollutants because it is considered the major constituent of pollution from the land surface.

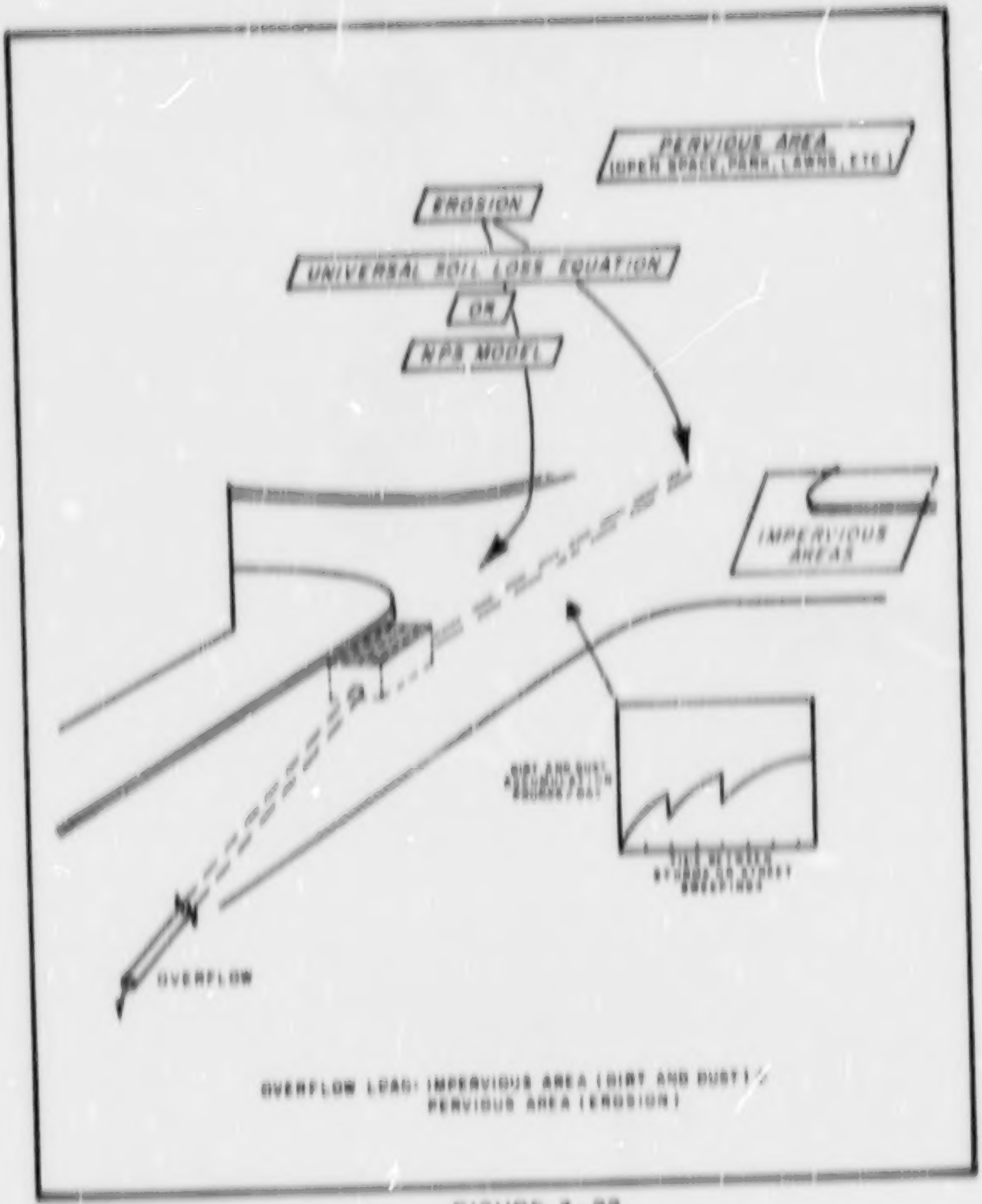

PERVIOUS AREA
(OPEN SPACE, PARK, LAWNS, ETC.)
EROSION
UNIVERSAL SOIL LOSS EQUATION
OR
NPS MODEL
IMPERVIOUS AREAS
DIRT AND DUST
TIME BETWEEN STORMS OR STREET SWEEPINGS
OVERFLOW
OVERFLOW LOAD: IMPERVIOUS AREA (DIRT AND DUST) /
PERVIOUS AREA (EROSION)

FIGURE 3-22
CHARACTERIZATION OF URBAN STORMWATER LOADS ACCORDING TO THEIR SOURCE (INSITU) GENERATION

It has been stated that the most important contributor of pollutants observed in urban runoff-overflows is the debris on the land surface (17,39). This occurs primarily as deposits in streets, gutters and other impervious areas draining to the street or storm sewers. Pollutants tend to accumulate on the land surface in many ways. Some of the most common accumulations occur as debris dropped or scattered by individuals, sidewalk sweepings, wastes and dirt from construction or renovation, remnants of household refuse dropped during collection or scattered by animals or winds, transportation residuals, and the fallout of particulate matter from the air. Regardless of the way in which pollutants tend to accumulate on the urban watershed, they can be generally classified into one of the following categories of street litter: rags, paper, dust and dirt, vegetation and inorganics. Based on street litter samples taken during a study in Chicago (17), the most significant category is dust and dirt except during the fall of the year when vegetation becomes the dominant component. It has been supposed that nearly all of the pollutants found in urban runoff can be associated with the dirt and dust component of street litter. However, the direct link between street dust and dirt accumulations and urban runoff quality is controversial (40). Competing contaminant sources contributing to runoff loads not accounted for by dirt and dust include:

1. Illicit and cross connections
2. Residuals scoured from pipe and channel networks
3. Neighborhood refuse and refuse management practices
4. Construction and erosion related activities
5. Air carried and deposited pollutants
6. "Natural" background loadings.

In addition, for combined sewer systems, storm overflows would carry contaminants contributed by raw sewage.

Significant monitoring efforts would be required to calibrate internal source generation and transport processes, so that they accurately represent local conditions. It has been suggested that 3 to 5 years of runoff data would be optimal in order to evaluate parameters under a variety of climatic, soil moisture, seasonal, and water quality conditions

(41). This is a significantly higher degree of effort than required in either the statistical method or the simplified stormwater simulator. Although estimates or default values are also available for use with these source generation techniques, they are much less readily checked and adjusted for local conditions by limited monitoring programs. In addition, there is a marked scarcity of data for use with these methods when compared with the amount of data available for the estimation of pollutant concentrations. For these reasons, methodologies which utilize source generation and transport mechanisms have not been included in the procedures recommended in this chapter for the estimation of urban storm loads. A suitable estimation of loads from non-urban areas, which provides a more detailed analysis than that outlined in Chapter 2, does require the use of these techniques. They are accordingly discussed further in Chapter 4 of this manual which addresses the estimation of non-urban loads.

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TO: Users of the Areawide Assessment Procedures Manual

The attached text constitutes the second of three mailings of the Areawide Assessment Procedures Manual. The titles of five sections which are included, and the correct placement of chapters in the Volume I binder and appendices in the Volume II binder, are described as follows:

Index Tab Notation	Text Title
Procedures for Nonurban Assessment	Chapter 4 - Assessment of Nonurban, Nonpoint Pollutant Sources and Loadings
Analysis of Stream Impacts	Chapter 5 - Analysis of Stream Impacts for Urban and Nonurban Sources
Monitoring	Appendix D - Monitoring Requirements, Methods, and Costs
Statistical Analysis Procedures	Appendix E - Documentation for Synoptic Rainfall Data Analysis Program - SYNOP
Glossary	Appendix J - Glossary

These sections of the Manual can be inserted into their correct places in the binders which you have previously received.

The distribution of this (second) mailing of portions of the Manual is being made to those individuals and/or companies who received the first mailing of the Manual (Chapters 1, 2, and 3 and Appendices A and C) and who completed and returned the registration form, EPA-231 (Cin.)(7/76) which was enclosed. This requirement to register as a recipient of th[illegible]l has been made for those who initially received the first mailing as well as those who subsequently requested it. Those who registered, therefore, are automatically receiving this mailing and will automatically receive future Manual additions.

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CHAPTER 4

ASSESSMENT OF NONURBAN, NONPOINT POLLUTANT SOURCES AND LOADINGS

4.1 Introduction

Areas requiring comprehensive planning for management of water quality almost always consist of a series of complex watersheds having a variety of land uses and hydrologic configurations. In many cases a relatively small percentage of the total land area is urban with the remaining nonurban areas a mixture of forested, agricultural, mining, or open lands. Assessment of nonpoint source pollutants (type and loadings) generated from urban areas was discussed in Chapter 3 of this manual and included consideration of both intermittent point sources (stormwater sewers) and diffuse sources (watershed drainage to surface waters). The following sections are intended to provide guidance in determining the type and magnitude of pollutants generated from various nonurban land uses.

Quantitative evaluation of the magnitude and impact of nonurban, nonpoint source pollutants is currently more art than science. Recently developed techniques, largely computer simulation models, describing watershed processes generating stream flow and associated water quality, are briefly described in Appendix A and will be slightly embellished in a later section but will not be discussed in detail. Application of any assessment methodology, simple or complex, should be attempted only with understanding of the important features of hydrology, soils, sediment transport, and land use. Equally important are the data bases required to evaluate the problem at various levels of resolution. The following sections will describe the general nature of nonpoint pollutant source, types, and loadings; and discuss the tools available to assess the magnitude and timing of loadings, and present in detail (with examples) a simplified approach for estimating loads based on the Universal Soil Loss Equation (1). Finally a concise summary of currently available specific information for each nonpoint source is presented.

4.2 General Characteristics of Nonpoint Source Loads

Essentially all nonurban, nonpoint source loads enter surface or groundwater through the overland or subsurface flow paths of the hydrologic cycle. Notable exceptions include man-made diversions and sewers for highway drainage or other specific hydraulic structures. NPS problems must be evaluated with these facts in mind. Stated simply, nonpoint source pollutants result from the interactions of the hydrologic cycle and land use. Land use and the associated environmental conditions determine the type, form, concentration, location, quantity, and time distribution of pollutants within a given watershed. These factors in turn determine the availability of each pollutant for transport to surface or groundwater via the hydrologic cycle. Finally, the energy and space-time distribution of each flow component (surface and subsurface) determine the amount of available pollutants reaching areas where water quality impacts are important.

Before numerical estimates of NPS loads are attempted or representative data presented, two qualitative relationships must be established: (1) the impact of land use on pollutant type and (2) the impact of the hydrologic cycle on pollutant transport.

4.2.1 Qualitative Relationship Between Land Use and Potential Pollutants

Land use can be conveniently defined at two levels for the purpose of relating man's activities to pollutants. The broad categories of agriculture, forests, mines, construction sites, waste disposal sites, and hydrologic modification areas define general land uses from which specific pollutants are emitted. Each of these land uses may have a wide array of specific activities of interest. For example, row-crop agriculture undergoes tillage, chemical application, harvest, and fallow periods during which specific pollutant loadings may occur.

The quality of water draining nonurban areas is also influenced by watershed properties that are independent of land use. The geological formations of an area influence the ionic constituents of both surface and groundwater. Similarly, untouched "wilderness" areas are subject to the same erosive and leaching processes acting on intensively managed areas. Usually, water coming from these areas is of high quality and need only be considered in estimating total loads to the system. Exceptions, no doubt, exist so hard and fast rules cannot be established.

4.2.1.1 Land Use Category - Pollutant Matrix

Most planning areas have ready access to broadly-defined land use data for initial analysis of NPS problems. For purposes of this manual, land use categories are defined as follows:

Construction--lands used for the construction of temporary or permanent facilities which are not directly linked to the watershed hydraulic network (see hydrologic modification).

Agriculture---lands used for production of crops or livestock in areas where water is supplied by rainfall.

Silviculture---lands used for production of timber or other forest products.

Residuals management---lands used for utilization or disposal of waste residuals from either public or private sources.

Hydrologic modification---lands used as sites for operations which modify the hydraulic network of the watershed.

Mining---lands used for the extraction of minerals from the earth and for on-site materials-handling roadway network.

In addition to these categories, others have been defined but have not been included here. The most notable is irrigated agriculture. The major problem associated with irrigated agriculture is quality of the return flow. However, in areas where pollution problems result from the practice of irrigated agriculture, other nonurban NPS problems are usually of little concern. Also, management options available for control of return flows are unlike those proposed for other sources.

The relationship of the above land use categories to potential pollutants is given in Table 4-1. The noted relationships do not imply that water quality problems automatically follow - it only shows those pollutants which have a known potential for becoming a water quality problem as a result of the land use.

TABLE 4-1

NONURBAN NONPOINT SOURCE POLLUTION MATRIX

Source	Pollutants						
	Sediment	Nutrients	Pesticides	Salinity	Organic matter	Micro-organisms	Trace metals
Construction	X	X	X		X	X	X
Agriculture	X	X	X	X	X	X	X
Silviculture	X	X	X		X		X
Residuals management	X	X			X	X	X
Hydrologic modification	X	X			X		X
Mining	X	X	X				X

4.2.1.2 Land Use Activity - Pollutant Matrix

Within each land use category, an array of human activity can be defined and presented as a matrix showing relationships between those activities and their potential for pollution. While a complete review of activity for each land use would be too lengthy for presentation here, it is useful to separate each land use category into the next level of resolution. Therefore, an activity-pollutant matrix for each category is provided for easy reference.

Construction: Usually, at any one time, only a small percentage of a watershed is experiencing construction activity. Because many construction activities are locally intensive, their sites relative to surface waters become very important, and the pollutant generating potential is best determined by site-specific analysis. If water quality impacts are to be either monitored or predicted, however, the scheduling of such activities must anticipate and reflect the short-term duration of active construction activities. For purposes of this manual, construction activities are elaborated as follows:

Clearing, grubbing, pest control---initial activities associated with site surveys, equipment and materials transport, removal of undesired vegetation, etc.

Rough grading---preparation of land surface for location and desired elevations of planned facilities.

Facility construction---actual construction.

Site restoration---final landscaping, clean-up, excess material removal, etc.

The relationship of these activities to potential pollutants is given in Table 4-2.

Agriculture: Agriculture is one of the two major land uses in the United States (forestry is the other). Nationally, over half of the total land area is classified as agricultural and is grossly divided into cropland, pastures, and open rangelands. Activity within this land use category includes the infinite array of operations performed during intense management of each agricultural enterprise. The major activities and associated pollutants resulting from crop and animal production are shown in Table 4-3.

TABLE 4-2

SUMMARY OF CONSTRUCTION ACTIVITIES AND ASSOCIATED POLLUTANTS

Activity	Pollutant								
	Sediment	Nutrients	Pesticides	Sanitary wastes	Petroleum products	Other chemicals	Trash	Cement	Metals, trace
Clearing, grubbing, pest control	X	X	X						X
Rough grading	X		X		X	X			
Facility construction			X	X	X	X	X	X	X
Site restoration	X	X							X

TABLE 4-3

SUMMARY OF AGRICULTURAL ACTIVITIES AND ASSOCIATED POLLUTANTS

Activity	Pollutant					
	Sediment	Nutrients	Pesticides	Organic material	Micro-organisms	Salts
Crop Production						
Seed bed preparation	X					
Chemical application	X	X	X			
Cultivation	X					
Harvesting	X			X		
Animal Production						
Concentrated feeding	X	X		X	X	X
Grazing - normal	X		X			
- overgrazing	X		X			
- along streams		X		X	X	

These activities remain quite broad and can be divided into considerably more operations. For example, there are a number of ways to prepare a seedbed which, in turn, may impact the quantity of pollutants available for movement by runoff or percolation. The kinds of pollutants should remain essentially the same, however. A complete discussion of various management systems within these categories is given in a recently published EPA-USDA report (2).

The common practice of land-spreading animal wastes has been omitted because it is included in the Residuals Management section.

Silviculture: Silviculture is defined as the cultivation of trees. For purposes of nonpoint source planning and control (and this manual), the definition is broadened to include all operations associated with the production, harvesting, and regeneration of timber. These operations are defined as follows:

Access---those activities required to access standing timber and transport harvested products (roads and trails).

Harvesting---those activities required to cut, transport, and collect logs for removal via the access system.

Reforestation---those activities required to prepare sites for reseeding or species conversion.

Intermediate growing practices---those activities required to control undesirable species, prevent fires, or otherwise promote growth.

Silvicultural operations are different from agricultural operations in two key ways: (1) rotations occur over 20 to 60 years, during which many of the above operations occur only for short time intervals, and (2) during any one time interval, only a portion of the total forested area is subject to the activities. These facts tend to mitigate nonpoint source pollutant loads, but significant problems may exist in some cases.

The relationship of silvicultural activities to potential pollutants is given in Table 4-4.

TABLE 4-4

SUMMARY OF SILVICULTURE ACTIVITIES AND ASSOCIATED POLLUTANTS

	Pollutants			
Activity	Sediments (Organic, inorganic)	Nutrients (Fertilizers, fire retardants)	Pesticide	Thermal pollution
Access	X			
Harvesting	X	X	X	X
Reforestation	X	X	X	
Intermediate Growing Practices		X	X	

Residuals Management: Residuals management practices are usually part of a complete waste management system. However, the primary concern of removing pollutants from waste streams often fosters neglect of the problems associated with disposal of the resulting residuals. Residuals include water and wastewater treatment sludges, septage effluent, municipal refuse, industrial wastewater treatment sludges, combustion and air pollution control residuals, dredge spoils, mining spoils, and animal wastes from confined feeding.

General statements about the nature and magnitude of the nonpoint source problems are difficult because the design and maintenance of each system varies significantly. For example, the practice of temporary dairy manure storage followed by land spreading on snow or frozen ground results in vastly different nonpoint loads than year-round spreading in the warmer areas of the country. Usually, however, two different problems arise - leaching of pollutants from buried or injected wastes and runoff or surface applied or incorporated wastes.

Residuals and their associated potential pollutants are given in Table 4-5.

Hydrologic Modifications: Hydrologic modifications in the truest sense would include all activities that alter the pathways of the hydrologic cycle. All construction activities and most other agricultural or silvicultural operations modify the hydrologic system in some way. For purposes of this manual, a more narrow definition is proposed: modifications occurring "in-stream" or "near-stream" such that there are direct links between the activity and water bodies. These activities include construction of dams and impoundments, channelization, dredging, and other in-water construction (bridges, docks, etc.).

The construction phases of hydrologic modifications result in essentially the same nonpoint source problems as other construction activities. Post-construction and maintenance may be more significant, however, because of the direct contact of the facility with the water body. For example, the impact of boat docking facility construction may be relatively short-term but subsequent waste oil, refuse, etc., from its use may be a continuous long-term source of pollutants.

TABLE 4-5

SUMMARY OF RESIDUAL WASTES AND ASSOCIATED POLLUTANTS

Activity	Nutrients	Organic material	Heavy metals	Micro-organisms	TDS	Suspended solids	Alkalinity	Acidity	Fly ash	Other	Odors
Wastewater sludge	x		x	x							x
Septage residual	x	x	x	x		x					
Water treatment sludge		x	x	x						x	
Municipal refuse		x	x	x	x		x	x			
Combustion and air pollution control residual							x		x	x	
Industrial waste sludge					x					x	
Feedlot manure	x	x	x	x		x					x
Mining waste								x		x	
Dredge soil		x				x				x	

The major hydrologic modification activities and their potential pollutants are given in Table 4-6.

Mining: Mining operations in certain regions of the country are the most significant watershed activity. The current and projected energy and mineral resource demands suggest a rapid growth of new mining and intensification of existing activities. The nonpoint source loads can be significant because of the dramatic change in the landscape and the characteristics of the newly exposed soils now subjected to erosion and leaching. Above and below ground mining result in somewhat different problems but both have certain activities in common that can be conveniently separated by their potential to yield nonpoint source pollutants. These activities are shown in Table 4-7.

Mine drainage is considered the most significant problem. In addition to sediments transported to streams by runoff, mineral constituents like acids, heavy metals, nutrients, and radionuclides have been measured in drainage water. Many of these pollutants result in acute toxicity problems for receiving waters as well as the common problems of nutrient enrichment, sedimentation, dissolved oxygen, etc.

4.2.2 Qualitative Relationship Between the Hydrologic Cycle and Pollutant Transport

The hydrologic cycle in large part determines the timing, volume, frequency, and quality of nonpoint source loadings. The land use activities described in previous sections determine the location and form of the various pollutants but any assessment or estimate of actual loadings must be made with proper recognition of the role of the watershed hydrologic response.

The watershed is best viewed as a system which yields outputs (including nonpoint source pollutants) in response to a series of inputs. Yevjevich (3) described this concept nicely when he wrote "Continental surfaces, underground acquifers, inland bodies of water, plants, and soils are environments with complex water inputs, environmental compositions, responses, and outputs. This environmental trinity, input-response-output, in combinations, mutual dependences, and feedbacks is defined as the hydrologic system." A systems description of agricultural watersheds is given by Stewart,

TABLE 4-6

SUMMARY OF HYDROLOGIC MODIFICATIONS AND ASSOCIATED POLLUTANTS

	Pollutant						
Activity	Sediment	Nutrients	Pesticides	Organic compounds	Trace metals	Thermal pollution	Other chemicals (silica, sulfide)
Channel modification	X					X	
Impoundments	X			X	X	X	X
Dredging	X	X		X	X		X
Maintenance facilities		X		X			

TABLE 4-7

SUMMARY OF MINING ACTIVITIES AND ASSOCIATED POLLUTANTS

Activity	Pollutant*							
	Sediment	Nutrients (fertilizers)	Pesticides	TDS	Sanitary wastes	Heavy metals	Acid wastes	Radio-active materials
Exploration	X							
Access and support facility construction	X				X			
Mineral extraction	X			X	X	X	X	X
Mineral processing	X			X	X	X	X	X
Mine closure	X	X	X	X	X	X	X	X

et al. (4) which can be generalized to describe any nonurban system. Figure 4-1 demonstrates the idea.

The nature of the inputs and outputs of the system in Figure 4-1 have important characteristics that must be understood before a complete assessment of nonpoint loadings can be made. Indeed, successful NPS control can only be achieved by knowing where the system is amenable to treatment and the magnitude and frequency of specific system inputs, properties, and outputs. Successful monitoring to determine the magnitude of NPS problems or the effectiveness of in-place controls is also keyed to the factors shown in Figure 4-1.

Precipitation inputs drive the system and, in large part, determine the total volume and time-distribution of runoff. In addition to their uncontrollable nature, precipitation and solar radiation are stochastic and spatially variable. The impact of these features on calibrating certain rainfall-runoff models was briefly discussed in Chapter 3. Precipitation measurement via raingage networks is a well-established science and historical records are available for many areas of the country. Statistical and mathematical techniques referred to earlier in Chapter 3 are also available to areally distribute measured point-rainfall data (5, 6, 7, 8, 9). Significant quantities of pollutants can enter the watershed via solution-stripping by precipitation. Typical pollutant types and loadings are given in section 4.2.3.

System inputs classified in Figure 4-1 as controllable are those substances or activities introduced by man. The land use activities described in the previous sections summarize these inputs. Location of inputs are variable but can be part of the controls introduced for reduction of nonpoint source loads. Indeed, it is only through this set of inputs that water quality improvements can be made.

As watershed system inputs are transmuted to system outputs, the system properties described in Figure 4-1 modify their behavior. Some of these properties, like soil type and topography, are for the most part fixed in both time and space. Others, like vegetative cover and drainage networks, are subject to change by the set of controllable inputs. Techniques to measure

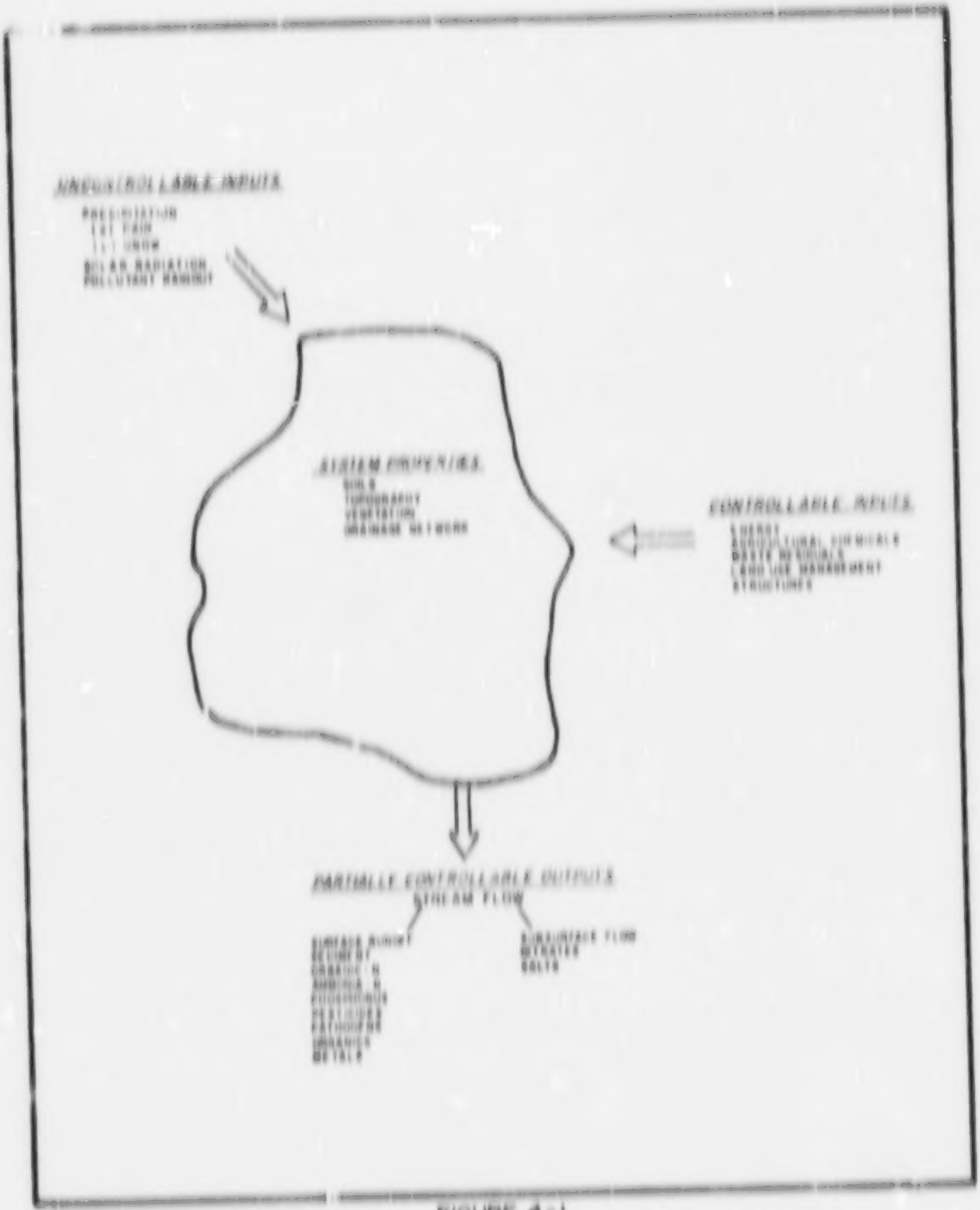


FIGURE 4-1
WATERSHED SYSTEM NON-POINT SOURCE POLLUTANT LOAD RESPONSE TO HYDROLOGY AND LAND USE

and specify these properties include interpretation of aerial photos, soils maps, topographical maps, and other data bases as described in Appendix C.

System outputs are described as partially controllable. This is an important point to consider when a control program is contemplated. Quantification of the degree of controlability possible is no trivial task and is directly related to the uncontrollable and stochastic nature of the system inputs. Obviously, an absolute standard or goal is impossible to achieve without violations for certain time periods, however small.

Another important feature of the system outputs of Figure 4-1 is the division between surface runoff and subsurface flow. The relative distribution of these flow components varies as a function of surface conditions, watershed size, and geological formations. In general, as a watershed increases in size, a greater proportion of the streamflow is determined by subsurface sources. Estimates of relative magnitudes are important to the correct interpretation of measured water quality data and the allocation of measured loads to their respective sources. Some of the NPS models described in section 4.3.4 are capable of predicting this relative distribution (10, 11). Other empirical hydrograph analysis techniques for this purpose are also available as described by Chow(12).

Resolution of watershed drainage into surface runoff or subsurface flow is important because most pollutants are transported in much greater quantities in one component of flow than in the other. The outputs shown in Figure 4-1 classify the major pollutants by their major modes of transport. There are, as always, exceptions to these rules as in those areas where extremely permeable (e.g., sandy) soil profiles exist or where large areas are impermeable. NPS controls also must be planned in recognition of flow distribution because many candidate practices (e.g., soil conservation practices) result in a shift in the relative distribution of flows and, subsequently, a new set of NPS pollutant loads must be analyzed. Interaction of surface and subsurface processes is a major consideration in the decision-tree analysis for selection of agricultural nonpoint source controls developed by Stewart et al. (2)

The impact of the hydrologic system is important in any attempt to measure the nature and extent of NPS loads through field sampling. Intensive, continuous sampling over short periods of time may measure little of the total extent of the problem. Runoff itself is stochastic as is the time between runoff events which, in turn, influences the quantity of pollutants available for transport. Of equal concern are the limitations inherent in grab sampling over longer periods in that peak loads may be missed entirely. A detailed presentation of monitoring methods and procedures is given in Appendix D of this manual.

4.2.3 Representative Nonurban Nonpoint Source Loading Data

Data from studies which attempt to measure nonpoint source loads vary over several orders of magnitude. This is not at all surprising when viewed in light of the possible variations in land use activities and the features of the hydrologic system acting on these activities. Indeed, the wide variation in data alone should serve as caution against relying heavily on extrapolation for assessment decisions.

Generally, there are three types of data bases available. They are (1) lysimeter or soil column studies, (2) small plot or individual field scale studies, and (3) drainage basin studies. Interpretation of data from these studies should be modified by the types of land use they represent, their location relative to the watershed system depicted in Figure 4-1, and the time period over which they were developed.

One other nonpoint source load not included in any of these is precipitation. In areas where surface waters constitute large areas, pollutant inputs via precipitation can account for a significant portion of the total load. Typical precipitation loading to land areas is given in Table 4-8.

Each of the three study types represents different components of the watershed system. Soil column or lysimeter studies represent only vertical movement of pollutants and effects of surface runoff, groundwater (shallow or deep) flow, or interflow (subsurface flow returns to surface runoff) are not included. Small plot or field scale studies represent direct surface runoff of pollutants and effects of groundwater flow, vertical movement, down-slope deposition, and different land uses, are not included. Portions of the

TABLE 4-8

NONPOINT SOURCE POLLUTANT LOADINGS FROM PRECIPITATION[a]

Type of Loading	Pollutant Range		
	Total Nitrogen	Total Phosphorus	Acids, pH
Areal loading lb/ac/yr	4.4-8.9	0.045-0.055	-
Concentration mg/l	0.1-12.8	0.005-0.10	4.3-5.6

[a] Source: (15, 24-28)

interflow effect may be observed. Drainage area studies include the effects of all flow components and different land uses. Drainage studies, depending upon the size of the basin they represent, may also reflect the effects of stream assimilation capacity. Also, larger drainage basins may be subject to groundwater export to or import from adjacent basins, making NPS pollutant mass balance calculations difficult.

Results of typical soil column studies are given in Table 4-9. Extrapolation of these data to NPS loads would result in overestimation of groundwater loads, especially for nitrogen. Such studies are very helpful, however, when investigating the impact of waste residuals, spoil materials, chemicals, etc., on the soil-plant-water complex. For example, the potential problems of heavy metal or pathogen leaching from areas (where runoff is controlled) on which municipal or industrial sludges are spread can be evaluated by analysis of similar data.

Small plot and field scale (small watershed) studies dominate the literature available on nonurban, nonpoint source loading. Such studies are very useful because they represent the relative impact of different land uses and land use activities (including management practices recommended for controls), and because they provide an estimate of direct surface runoff water quality. Generally, the larger the area included in the study, the more realistic the extrapolation of the data because more components of the hydrologic system are included.

Data from typical studies representing various land uses and pollutants are included in Tables 4-10 through 4-13. Comparison of the areal contribution data from these studies with similar data from the soil column studies illustrate the moderation provided in small watershed studies by the increased geographical scale and the inclusion of more watershed processes over those provided by soil column studies.

Data collected during drainage basin studies are usually considered to be most meaningful in evaluating the water quality impact of nonpoint source loads. Two conditions are necessary to make such studies suitable for water quality impact assessment. First, the measured water quality must be determined primarily by processes occurring in or on the land surface and

TABLE 4-9

AGRICULTURAL NONPOINT SOURCE LOADING FROM SOIL COLUMN STUDIES[a]

	Nitrogen yield, lb/ac/yr			Phosphorus yield, lb/ac/yr		
	Number[b]	Mean	Range	Number[b]	Mean	Range
Total	15	25	0.3-98	9	1.04	0.05-6.9
Inorganic	28	17	0.3-73	6	0.47	0.01-2.2

[a] Extracted from Chapter 2, Table 2-12

[b] Number of studies.

TABLE 4-10

AGRICULTURAL NONPOINT SOURCE LOADING DATA FROM SMALL PLOTS (0.02-0.80 ACRES)[a]

Crop	Management system	Pollutant loss, lb/ac/yr NO_3^--N	 NH_4^+-N	 Inorganic P
Corn	Return residue & rye as cover crop	1.25	0.29	0.115
	Return residue & rye as cover crop	0.35	0.12	0.04
	Residue burned, no cover crop	2.19	0.88	0.436
	Residue burned, no cover crop	0.35	0.18	0.14
	No-till	10.22[b]		1.44
	Conventional	9.64[b]		0.20
	Continuous corn silage	7.51[b]		0.48
	Continuous corn silage cover crop	8.37[b]		0.53
Beans	Return residue	1.30	0.36	0.16
	Residue removed	26.0	0.44	0.33
Soybeans	Continuous field cultivator	7.61[b]		0.44
	No-till	4.84[b]		1.84
Wheat	Return residue plus rye grass & alfalfa cover crop	0.83	0.37	0.15
	Return residue plus rye grass & alfalfa cover crop	0.44	1.15	0.18
	Residue burned, no cover crop	1.01	0.32	0.28
	Residue burned, no cover crop	0.53	0.13	0.07
Meadow		1.40[b]		0.43

[a] Source: (27,30)

[b] Contains NO_3^- + NH_4^+-N.

TABLE 4-11

TYPICAL PESTICIDE LOADINGS MEASURED ON SMALL PLOTS (44-5700 FT^2)^a

[illegible]

TABLE 4-17

AGRICULTURAL NONPOINT SOURCE LOADING DATA FROM SMALL WATERSHEDS (0.7-150 ACRES)[a]

Crop	Management System	Pollutant loss, lb/ac/yr					
		NO_3-N	NH_4-N	Kjeldahl N	P[b]	Suspended Solids	COD
Corn	Contour	1.29	0.85	2.96	0.26		
	Contour	0.47	0.31	22.46	0.52		
	Contour	0.84	1.30	41.55	1.15		
	Contour[c]	2.05	1.38	5.23	0.442		
	Contour[c]	1.50	0.37	31.02	0.923		
	Contour[c]	1.17	1.88	61.66	1.000		
	Terraced[c]	0.21	0.11	0.28	0.08		
	Terraced[c]	0.13	0.03	0.46	0.018		
	Terraced[c]	0.14	0.52	6.28	0.257		
	Corn & Oats rotated	0.33	-	0.81	0.27	255	43
Brome Grass	Rotation/-grazing	1.02	0.59	0.46	0.224		
	Rotation/-grazing	0.15	0.08	0.19	0.072		
	Rotation/-grazing	0.84	0.38	2.58	0.456		
	Hay/grazing	0.21	-	0.65	0.09	3.6	12
Pasture	Grazing	0.36	-	1.06	0.22	10.5	25

[a] Source: (32,33)

[b] Total loss values represent the inorganic P of the solution and the $NaHCO_3$-extractable P of the sediment.

[c] 2.5 times recommended rate applied.

TABLE 4-13

TYPICAL PESTICIDE LOADINGS MEASURED ON SMALL WATERSHEDS[a]

Pesticide	Amount applied (lb/ac)	Type of application[b]	Crop	Plot size, ac	Pesticide loss in runoff (lb/ac)	Range of pesticide loss in runoff increments
Atrazine	3.0	S	Corn	1.7-3.8	0.08	1.77-755 ug/g sediment
Dieldrin	5.0	Inc.	Primarily Corn	1.7	0.00055 water 0.11 sediment	1.9-20 ug/l water 1.6-24 ug/g sediment
	5.0	Inc.	Primarily Corn	2.7	0.055	0.4-4.1 ug/l
Picloram	2.5	F	Grass	3.0	0.00005	7-12 ppb
Propachlor	6.0	S	(Corn Surface)	1.7-3.8	0.139	117-481 ug/l water
Toxaphene	9.0	F	Cont. Cotton	38.5	0.0064	<10-28 ug/l
Trifluralin	0.98	Inc.	Cont. Cotton	38.5	0.00176	
2,4,5-T	2.5	F	Grass	3.0	0.0005	7-26 ppb

[a]Source: (31,34)

[b]S=Surface; Inc. = Incorporated; F = Foliar

not in the stream. In other words, the data should reflect pollutant loadings only, rather than a combination of loading and stream processes. (If all pollutants were conservative this would not be a problem.) Second, the measured output should be from a "hydrologically closed" watershed. That is, interbasin transfer of water (and pollutants) should be minimum or at least measurable.

Ideally, a number of basins having only one land use should be studied. However, basin studies tend to lump the effects of land use. A recent EPA study (13) analyzed a number of drainage basins and attempted to correlate general land use to measured water quality. Results from this and other studies are summarized in Tables 4-14 and 4-15.

4.3 General Characteristics of Nonpoint Source Load Estimation Methods

The previous section discussed the various kinds of loading data available and evaluated their usefulness in assessment studies. The importance of data interpretation within the hydrologic system framework was stressed. For assessment studies there are various approaches available for estimating nonurban, nonpoint source loads. The evaluation of these techniques must also be made within the hydrologic system framework and associated land use configurations. The following section includes a general discussion of the basic properties common to most loading methods (models), followed by a more detailed description of key models now available for application to assessment studies.

Mathematical modeling of complex phenomena is a rapidly growing science for which few widely recognized standards or definitions exist. At the risk of violating the sensibilities of a few modeling practitioners (perhaps even more than a few), the following definitions are offered:

Empirical methods---calculation procedures based on analysis of data or a certain known relationship among variables.

Deterministic methods---models based on a rigorous representation of known relationships (physical or mathematical).

Stochastic methods---models based on the concepts of probability theory and the idea that future events are determined by random processes.

GEOLOGIC CLASSIFICATION AND MEAN VALUES FOR STREAM NUTRIENT CONCENTRATIONS AND EXPORTS FROM 223 SUBDRAINAGE AREAS IN THE EASTERN UNITED STATES[a]

Land use	Geologic classification and grouping code(s)	Number of subdrainage areas	Concentrations, mg/l T-P	O-P	T-N	I-N	Exports, kg/km²/yr T-P	O-P	T-N	I-N
Forest		[illegible]								
	Sedimentary; some or all limestone (33)	[illegible]	0.031	0.004	0.860	0.297	6.4	3.6	404.7	159.6
	Sedimentary; without limestone (29)	17	0.024	0.007	0.766	0.337	8.0	4.0	407.6	192.2
	Sedimentary; all (33, 29)	31	0.022	0.006	0.825	0.300	7.4	3.9	407.3	171.5
	Predominantly sedimentary (33, 34, 29)	35	0.022	0.006	0.828	0.302	7.3	3.9	402.3	200.1
	Igneous, volcanic origin (39)	0	-	-	-	-	-	-	-	-
	Metamorphic (40)	16	0.027	0.007	0.222	0.107	10.3	4.6	177.4	45.2
	Igneous, plutonic origin (35)	0	-	-	-	-	-	-	-	-
	Igneous and metamorphic (37, 40)	16	0.027	0.007	0.227	0.103	10.3	4.6	242.1	74.0
	Predominantly igneous and metamorphic (37, 41, 42, 40)	22	0.026	0.007	0.425	0.105	8.7	4.5	300.7	90.7
Mostly Forest		170								
	Sedimentary; some or all limestone (33)	[illegible]	0.037	0.015	1.156	0.400	16.5	6.7	472.1	210.7
	Sedimentary; without limestone (29)	49	0.055	0.014	0.897	0.390	18.7	6.9	443.8	203.2
	Sedimentary; all (33, 29)	103	0.054	0.014	0.946	0.385	17.2	6.6	458.0	194.3
	Predominantly sedimentary (33, 34, 29, 23, 24, 25)	119	0.036	0.013	0.930	0.374	17.2	6.3	456.3	186.7
	Igneous, volcanic origin (39)	0	-	-	-	-	-	-	-	-
	Igneous, volcanic origin (frequent but non-dominant) (33, 40)	4	0.056	0.016	1.073	0.129	15.1	6.2	552.2	115.5
	Metamorphic (40)	11	0.035	0.014	0.782	0.177	20.7	6.2	452.0	306.0
	Igneous, plutonic origin (35)	1	0.026	0.010	0.850	0.136	7.4	2.6	299.5	78.2
	Predominantly igneous, plutonic origin (35, 32, 34)	6	0.052	0.023	1.040	0.327	23.6	9.1	474.7	154.6
	Igneous and metamorphic (35, 40, 45, 35, 34)	20	0.056	0.014	0.766	0.269	19.2	6.2	427.7	149.8
	Predominantly igneous and metamorphic (41, 42, 42, 45, 45, 35, 32, 34)	32	0.055	0.014	0.827	0.364	19.2	6.2	455.2	152.5
Agriculture		51								
	Sedimentary; some or all limestone (33)	[illegible]	0.136	0.059	4.315	3.266	30.3	11.4	798.8	748.3
	Sedimentary; without limestone (29)	11	0.127	0.051	3.687	2.735	23.6	10.3	895.4	668.2
	Sedimentary; all (33, 29)	41	0.135	0.058	4.235	3.190	29.7	11.1	982.3	738.6

Abbreviations: T-P = Total Phosphorus; O-P = Orthophosphorus; T-N = Total Nitrogen; I-N = Inorganic Nitrogen

[a] Omernik (1976)

TABLE 4-15

RUNOFF AREAL LOADING RATE - POUNDS/SQUARE MILE/DAY[a]
(Average Range)

Land Use	Total Nitrogen	Total Phosphorus	BOD_5	TSS
Agriculture	15 (1.9-58)	1.0 (0.05-3.9)	40 (6.3-57)	2500 (449-6594)
Forest	4 (1.3-16)	0.25 (0.01-1.4)	8 (6.3-11)	400 (71-620)
Pasture	8 (3.9-13.3)	0.5 (0.4-1.0)	17 (9.4-27)	670 (19-1320)
Feedlots	1700 (1080-2200)	370 (200-610)	-	-

[a] Extracted from Chapter 2, Table 2-13

Simulation methods--models containing components of each of the above methods which attempt to simulate the behavior of processes known to influence the variable of interest.

Regression equations like the Universal Soil Loss Equation and the urban runoff equations used in Chapter 3 are examples of empirical approaches. The data bases upon which empirical models are built determine their ability to satisfy the needs of any given task. Use of such methods in solving problems outside the range of the original data base is risky and should be done only with full recognition of the possible errors.

Deterministic models are most elegant in their treatment of any problem. However, for NPS load assessment studies, the current lack of understanding of nonurban watershed dynamics and the apparent inability to measure all the necessary parameters make such models almost impossible to use. Some associated specific problems can be solved in this manner. Pipe and rigid-boundary, open-channel flow are amenable to deterministic modeling.

Stochastic models are becoming popular tools in water resource problem-solving (14). These methods require large amounts (in space and time) of data generally not available for water quality assessment studies. But when prediction of precipitation and streamflow is needed, and data for long periods of record are available, such techniques can be effectively applied.

Simulation models are especially attractive for use in nonpoint source assessment because they permit application of the state-of-the-art for each process of interest. For example, erosion modeling is still largely an empirical science, while overland flow can be treated deterministically. Simulation can combine both approaches to estimate sediment transport. Another key feature of simulation models is their ability to predict system responses from system changes - an obvious need when evaluating alternative future policies.

Application of any of the above models to estimation of NPS loads requires calibration and testing (some prefer the term verification). For some empirical models, like regression equations, both are trivial tasks because the exact form of the model is determined by the available data. The test for "accuracy" is inherent and is reflected in the statistical measures of correlation. Other empirical models like the urban loading method presented in Chapter 3 are calibrated by applying the model to the measured data and calculating the parameters and coefficients which appear as unknowns in the equations. Empirical models will yield better results when tested against data from areas having the same properties as those associated with the calibration data set. Indeed, the major weakness of empirical approaches is their inability to accomodate changes in the watershed. Calibration of deterministic models consists of estimating the physical constants applicable to the system under study. Testing is inherent because deterministic formulations are developed from well-understood, thoroughly-tested theory. Simulation models require calibration through trial and error or least-squares fitting procedures. The deterministic features of simulation models require inputs that are independent of time-varying, measured data (e.g., flow, water quality). Testing is normally accomplished by split-sample procedures. That is, part of the data set is used for calibration to adjust model parameters and the remaining data are simulated to determine how well the model predicts "future" loadings.

Nonurban, nonpoint source models can also be evaluated by comparing their properties to the watershed-hydrologic system described in section 4.2.2. This can be done for all models regardless of their classification among empirical, deterministic, stochastic, or simulation. Three fundamental properties can be listed: (1) spacial resolution, (2) temporal resolution, and (3) transport assumptions. Any NPS loading method or model can be evaluated by separation according to these properties. The resulting information is useful in determining the appropriate model for application to any given problem. The following sections describe these properties.

4.3.1 Spatial Resolution

Data are used during the development of most loading models and the resulting model spatial scale is directly related to the spatial scale of the data sources. Spatial scales for NPS assessment models are almost the same as those for the data described in section 4.2.3 with one excepion. Models for conditions at a point, corresponding to the soil column studies, have limited application to NPS loading estimation and are not included here. Such models may be useful in studying leaching problems from residuals disposal areas or for investigating the impact of certain practices on the soil-plant-water complex but these are not normally a part of a general NPS assessment study.

NPS loading models have been developed for field scale or small plot areas, first-order watersheds, and complex drainage basins. Figure 4-2 illustrates these three levels of spatial resolution.

Field Scale: The field scale unit is the basic building block for the larger area models. The "field" varies in size from a few to a few hundred acres. Runoff loads calculated from such areas are limited to direct surface runoff and a small portion of the shallow, subsurface flow (interflow). Only single land uses are represented but these models are ideally suited for evaluating the relative effectiveness of alternative management practices. For example, all soil conservation farm planning is based on techniques developed for field size areas.

Models having only a field scale spatial resolution are subject to the same caveats as the concomitant data bases. Only a portion of the hydrologic system is represented and certain attenuating processes (sediment deposition, adsorption during subsurface flow, etc.) are not included. As a result, the sum of field loadings for a large basin usually exceed measured water quality at a point downstream in the same basin.

First-Order Watershed: A first-order watershed is hydrologically defined as any watershed which is drained by a stream having no tributaries above its confluence. For purposes of this manual, a modification to that definition is proposed - a first-order watershed is any watershed whose water quality is not influenced by in-stream processes (chemical, biological, etc.). The size of such watersheds varies for different regions but is generally limited to less than two square miles. Several land uses are possible at this scale, so the models should have the capability for predicting multi-land use loadings. All components of the hydrologic cycle can be observed in first-order watersheds so that models should (not all do) predict loadings in both surface and subsurface flows.

Complex Drainage Basin: Estimating NPS loading at some point "downstream" in a large watershed having varying land use and a complex hydraulic drainage network cannot be accomplished unless in-stream water quality changes are

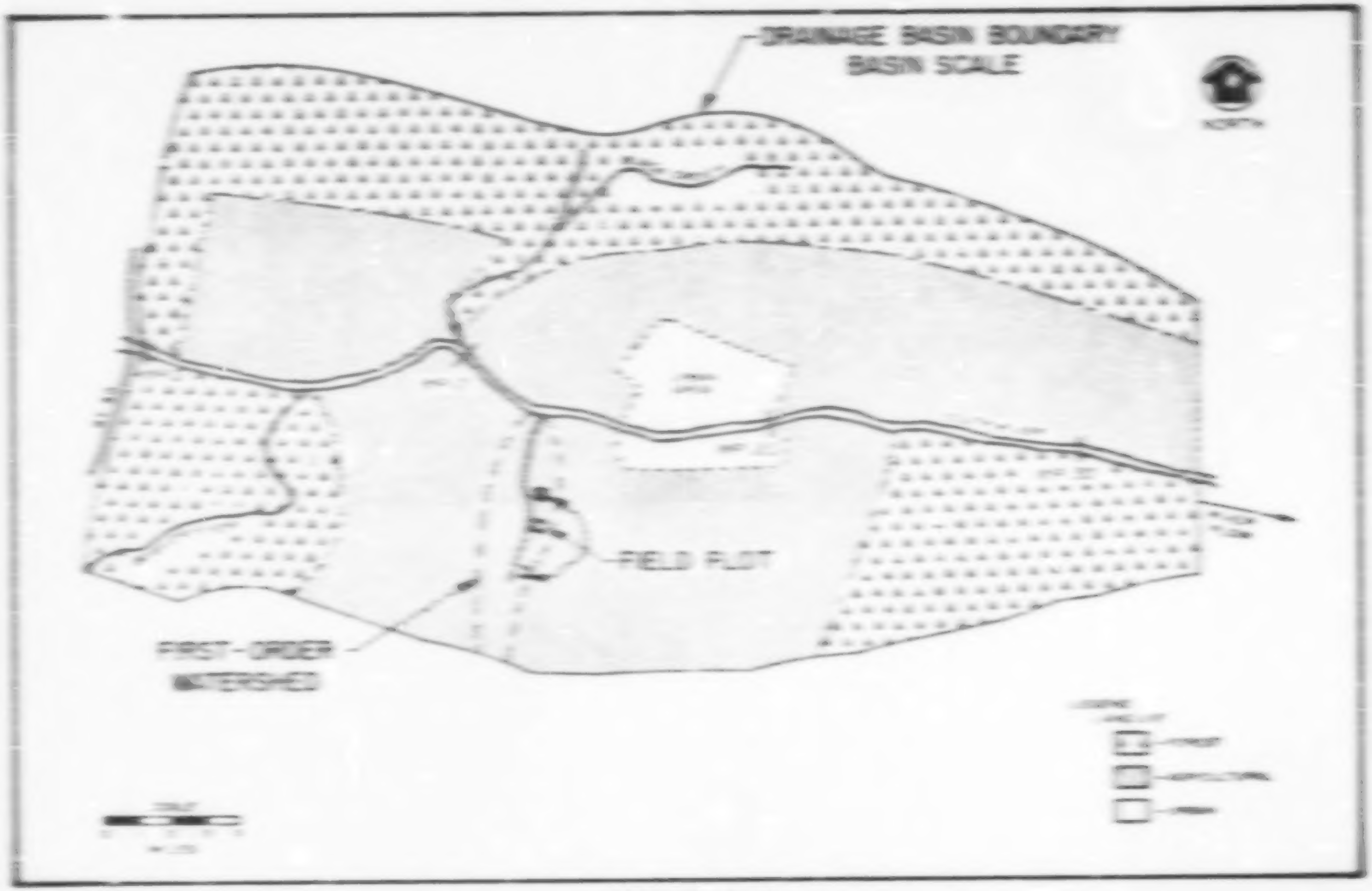


FIGURE 4-2
"SOUTH RIVER, U.S.A.)
HYPOTHETICAL EXAMPLE
SPATIAL SCALE COMPARISON

included as part of the model. For this reason, no generalized "loading only" model has been developed and tested. Indeed, testing might well prove impossible. Empirical models and regression equations can be developed with data collected at any downstream point but the result is an equation that lumps together land use and water quality impacts. The additional set of factors included in the model make accurate extrapolation almost impossible. It is possible, however, to construct models based on first-order watershed scale calculations which may provide good estimates of loads with the accompanying assumption that such loads are conservative. Although these models are difficult to verify, their outputs can be useful in evaluating the relative benefits of various control alternatives applied to large areas.

4.3.2 Temporal Resolution

The second fundamental property of NPS loading models is the time period over which they predict loads. Again, comparison of these time intervals with the behavior of the watershed system response described in section 4.2.2 provides insight into the most appropriate choice of analysis methodology. Three approaches representing different time intervals are available as follows: (1) single event, (2) annual average, and (3) continuous simulation over any specified time interval. Figure 4-3 illustrates the output of each approach. Each time interval will now be examined in more detail.

Event Models: Event models are predicated on the assumption that a "design" load can be estimated and its water quality impact determined. This "worst case" analysis has been popular in hydraulic structure design but its use in nonurban, NPS loading estimation is currently quite limited. The major difficulty with this approach is estimation of the antecedent conditions, especially those related to pollutant availability for transport by runoff. Recall from the earlier discussion of land use that land use activities and their timing combine with various environmental conditions to determine the concentration, form, and location of pollutants for subsequent transport via the hydrologic cycle. Since these processes occur between individual events, their results must be established as boundary conditions for each model run.

Annual Average Models: The major water quality impact of some pollutants is exerted over long time periods. For example, nutrient loads to a large impoundment may be adequately described by the total annual load. If sediment

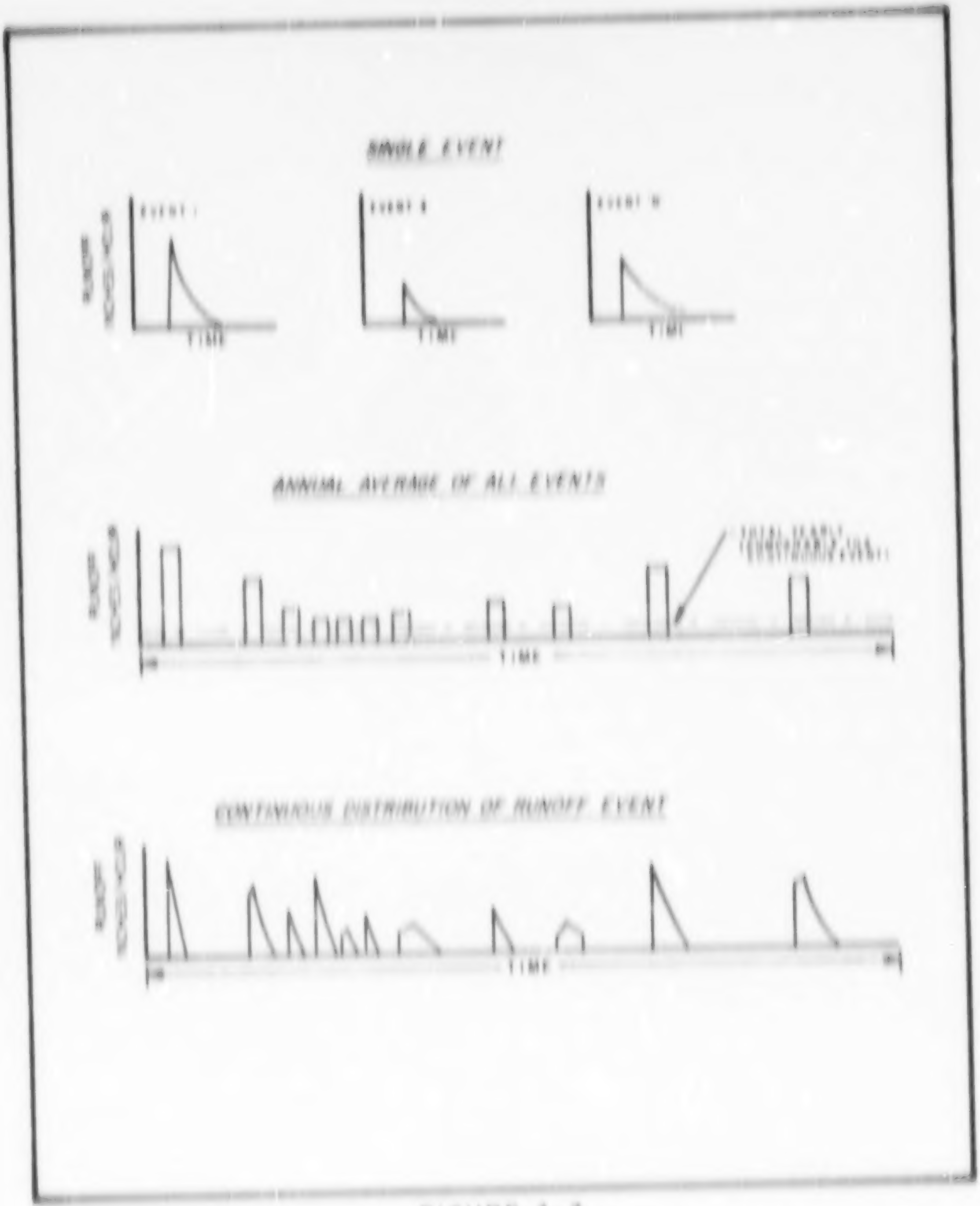

SINGLE EVENT
EVENT 1
TIME
TIME
TIME
ANNUAL AVERAGE OF ALL EVENTS
TIME
CONTINUOUS DISTRIBUTION OF RUNOFF EVENT
TIME

FIGURE 4-3
TEMPORAL RESOLUTION OF RUNOFF PROCESS

deposition is the problem, the total annual load may suffice for an assessment decision. For those situations (and for others not so well suited) models have been developed that predict annual average loadings. In some cases, total water yield is estimated as the transporting medium, while in others, sediment yield is used as the transport medium. Most notable among these models are those based on erosion prediction by the Universal Soil Loss Equation (15). Annual average loading can be distributed on a daily basis as was done in the examples of Chapters 2 and 3.

Continuous Simulation Models: The most complete description of the watershed response is provided by models that attempt to predict all loadings by continuously simulating the hydrologic cycle and its interaction with land use activities. Such techniques require more data inputs and calculation time. The need to predict loadings in this manner may depend on the pollutants of interest and their anticipated impact. For example, pollutants like pesticides that exhibit a short-term water quality impact from peak loading can hardly be predicted by annual average techniques or event models that require a priori specification of the timing of peaks in pollutant availability on the watershed. An added advantage of continuous simulation is the ability to predict event or annual average loadings. It is, of course, possible to construct a continuous model from single event models by addition of the between event processes.

4.1.3 Transport Assumptions

The hydrologic cycle provides the pathways and energy to transport pollutants to surface or groundwater. Pollutants will be transported with the sediment carried by overland flow or dissolved in both overland and sub-surface flow. The physical-chemical processes that determine the relative distribution of pollutants between particulate and dissolved forms are poorly understood and even more difficult to describe mathematically to the point where the theory can be incorporated into NPS loading models. A recognition of the partitioning phenomenon must be made, however, in both interpreting measured data and predicting loads via models. Models have been designed that assume all pollutants are attached to (or behave as) sediment while others attempt to partition pollutants between the two transporting media.

4.3.1.1 Sediment-Based Transport

Sediment-based transport models assume pollutant loads are proportional to sediment loads. Loads are calculated by predicting sediment loss and applying the proportionality relationships for each pollutant. Because sediment is transported by direct surface runoff, sediment-based models are more useful in predicting pollutants associated with soil surface conditions. Dissolved constituents are not necessarily ignored, however. Sediment transport is also proportional to runoff volumes and if the relative distribution between water and sediment does not change, total pollutant losses can be estimated. That is, if the relationship between pollutants and sediment is determined by measurements taken for the total runoff (water and sediment) it may be possible to estimate total loads by only predicting sediment losses.

Two problems arise from the sediment-transport assumption. First, much larger quantities of water than sediment appear in the drainage from watersheds. If dissolved constituents are ignored, significant NPS loads will also be ignored. The fact that subsurface flow accounts for a higher percentage of the total runoff as the watershed size increases further highlights this problem. Nitrate loading estimates are not included in sediment-based models. The second problem arises from the interaction of pollutants and sediment particles. Sorption is a function of surface area which in turn is determined by the particle size. Relationships of surface area to textural classes have been developed by Frere et al. (11). Using a three-level distribution, the specific surface area can be calculated by:

$$SS = 200\ (\%Cl) + 40\ (\%Si) + 0.5\ (\%Sa) \qquad (4\text{-}1)$$

where SS = specific surface area, m^2/g
%Cl = clay content of soil, fraction of total
%Si = silt content of soil, fraction of total
%Sa = sand content of soil, fraction of total

Equation (4-1) shows that the clay content of soil largely determines the surface area available for interaction with pollutants.

The impact of equation (4-1) on sediment-based loading models results from the mechanics of the erosion process. Analysis of eroded and in situ soil samples for a given area show that erosion is a selective process resulting in a greater percentage of finer material (clays, silts) in the eroded soil than in the original material. The net result is a different relationship between pollutants and sediment in runoff than in the soil profile. Most erosion models predict only gross soil movement. That is, no distinction is made among soil particle sizes. To accommodate this problem, an "enrichment ratio" is often applied to predicted loads to increase the concentration of pollutants in or on eroded soil. Numerical estimates of the enrichment ratio are included in section 4.4.5.

Sediment-based transport models can also estimate loadings for pollutants that behave like inorganic sediment during transport. Organic matter (plant residues, animal wastes, etc.) and crystalline or precipitated chemicals may not be sorbed to soil particles but may be part of the total suspended solids measured in runoff water. If such materials have specific gravities less than inorganic sediments, their presence will increase the measured enrichment ratio because of preferential movement by runoff water.

4.3.3.2 Partitioned-Based Transport

Land use activities combined with environmental conditions within a watershed determine the type, form, and distribution of pollutants. A whole series of complex processes combine to determine for any given pollutant the relative distribution between dissolved and particulate forms. In some cases the distribution is a simple one-way shift from particulate to dissolved as a result of decay or leaching. Usually, however, equilibrium is reached with shifts dependent on pollutant concentration and environmental conditions.

If partitioning processes are included in loading models, the dissolved and particulate loads can be calculated. For example, ammonium (NH_4^+) is transported in both runoff water and adsorbed on sediment. If partitioning constants for NH_4^+ are known for a given soil, loads in water and sediment can be estimated. Currently available models assume adsorption reaches instantaneous equilibrium and represent the process by a variation of the Freundlich equation. The Freundlich equation is:

$$C_s = KC^{1/n} \qquad (4-2)$$

where C_s = pollutant adsorbed per unit weight of soil

k, n = empirical constants

C = pollutant concentration in dissolved phase

Note that when $n = 1$, equation (4-2) reduces to the linear case and a simple partitioning coefficient, k, characterizes the process.

The addition of partitioning capability to NPS loading models obviously enhances their ability to yield reliable results. Unfortunately, the data requirements, model sophistication, and computer run-time requirements also increase. Considerable thought should be given to design of the study plan if such models are chosen for assessment studies so that the most efficient model use can be achieved. Optimal strategies are impossible to specify now because so little experience is available to draw upon.

4.3.4 Classification of NPS Models

Nonpoint source models should be evaluated in the same manner that measured runoff data are analyzed. Namely, how do model properties and capabilities compare with the behavior of the watershed system depicted by Figure 4-1. A complete analysis of each available model along with sample runs, etc., is beyond the scope of this manual, but it is possible to classify the key models or techniques according to the fundamental properties (spatial, temporal, and transport) of importance. Table 4-16 shows the classification of selected NPS loading models.

Appendix A, Model Applicability Summary, presents a brief summary of major stormwater and water quality models and includes some discussion related to two of the models shown in Table 4-16 (AGRUN and ARM). For those models not included in Appendix A, a similar analysis is provided in the following sections.

NPS: The Nonpoint Source Pollutant Loading Model (NPS) was developed by Hydrocomp, Inc., for EPA. The model was specifically designed for use in planning studies and is compatible with existing water quality impact models. The model is comprized of subprograms to represent the hydrologic processes in a watershed, including snow accumulation and melt, and the processes of pollutant accumulation, generation, and washoff from the land surface. The hydrologic components, derived from the Stanford Watershed Model, have been

TABLE 4-16

SELECTED CHARACTERISTICS OF NONURBAN NONPOINT SOURCE MODELS

Characteristic	Model				
	NPS	AGRUN	ACTMO	ARM	MRI
Spatial Resolution					
Field scale	X		X	X	X
First-order watershed	X	X	X	X	X
Basin		X			X
Temporal Resolution					
Runoff event	X	X	X	X	
Annual average	X		X	X	X
Continuous	X		X	X	
Transport Assumption					
Sediment	X	X			X
Partitioned			X	X	
Reference	20	35	11	10	15

previously tested and verified on numerous watersheds across the country. The sediment and pollutant transport components have been tested on several urban and rural watersheds for selected pollutants and are currently undergoing additional testing. The simulation of pollutants is based on sediment as an indicator. Erosion processes are simulated and the resulting loads are converted to pollutant loads by user-specified "potency factors" that indicate the pollutant strength of the sediment for each pollutant simulated.

The NPS model can simulate loads from a maximum of five different land uses in a single production run. In addition to runoff, water temperature, dissolved oxygen, and sediment, the NPS model can simulate up to five user-specified pollutants from each land use category.

Documentation of the model, complete with a user manual and program listing, is available from EPA in a report entitled "Modeling Nonpoint Pollution From the Land Surface," EPA-600/3-76-083, (July 1976).

ACTMO: The Agricultural Chemical and Transport Model (ACTMO) was developed by the Agricultural Research Service, U.S. Department of Agriculture. The model consists of three components simulating hydrology, erosion and sedimentation, and interactions of agricultural chemicals (fertilizers and pesticides) with the soil-water-plant system. The USDAHL-74 model (16) was used for the hydrologic component and the Universal Soil Loss equation was modified to generate erosion/sedimentation. ACTMO is one of two models (ARM is the other) that simulates the partitioning of pollutants between water and sediment. The hydrologic model has been tested on several watersheds, the sediment model has been tested in two locations and the chemical transport model is essentially untested. Current status of model development is unknown.

Documentation of the model is available from ARS-USDA in a report entitled, "ACTMO - An Agricultural Chemical Transport Model," ARS-H-3, (June 1975).

MRI: The Midwest Research Institute (MRI) developed for EPA a series of loading functions for assessment of water pollution from nonpoint sources. These loading functions assume the form of algebraic equations that can be solved analytically without the aid of computers. Functions for essentially all nonpoint sources and pollutants are included. For most cases, modifications of the USLE are used. Daily loads are calculated from annual average estimates. In addition, a methodology is proposed for estimating the maximum and minimum thirty-day loads. This set of functions is consistent with the loading models for urban areas in Chapter 3 and will be further expanded via examples in section 4.5.

Documentation of each loading function complete with supporting data and references is included in the EPA report entitled "Loading Functions for Assessment of Water Pollution From Nonpoint Sources," EPA-600/2-76-151, (May 1976).

4.4 Nonpoint Source Loading Methods Based on the Universal Soil Loss Equation (USLE)

Most nonpoint source models estimate pollutant loads by relating pollutants to sediment. The problem is thus reduced to calculating erosion and sedimentation. The Universal Soil Loss Equation (USLE) is an entrenched analytical tool used for the purpose of soil conservation planning. Because of its wide-spread use and successful testing over the years, many NPS loading models have been built around it. Both desk-top analyses like the MRI loading functions and computer simulation models like STORM, AGRUN, and ACTMO, make use of the equation in one way or another. Future development of NPS loading models will likely continue inclusion of USLE variations. For these reasons, the basic equation, its limitations, extensions, and associated data bases are included in the following sections. The descriptions are somewhat abbreviated to avoid needless repetition of excellent references on the subject (1, 2, 17).

4.4.1 The Equation

The equation is:

$$A = RKLSCP \qquad (4-3)$$

where A = average annual soil loss in tons/acre
R = rainfall and runoff erosivity index
K = soil erodability factor
LS = dimensionless topographic factor representing the combined effects of slope length and steepness

C = the cover and management factor

P = factor for supporting practices

Note that equation (4-3) includes factors for precipitation (and to a lesser extent, runoff), soil type, topography, vegetative cover, and structural controls. Although the form of equation (4-3) is often argued, most of the erosion processes are included. The influence of runoff on erosion is only partially implicit in R because of the way in which the data were correlated. That is, R is calculated directly from rainfall but field data against which R was correlated included the lumped effects of rainfall and runoff. A major weakness still prevails if the size of the area expands beyond a field of a few acres. The influence of runoff in channels on erosion and deposition is not included. When the equation is used for calculating annual average loads at a given location, R, K, and LS are fixed, areal properties and yearly variations in sediment loads result solely from changes in management or structural controls.

Perhaps the most attractive feature of the USLE, in addition to its ease of use, is the data base available to aid the user in estimating the equation factors. The U.S. Department of Agriculture's Soil Conservation Service uses the equation on a nation-wide basis and considerable effort has been devoted to determination of factors for a wide array of geographical locations, soil types, cropping systems, topographical configurations, and tillage operations. Detailed guidance on selection of the most appropriate numerical values for each factor is included in several of the references given in the list of references for this chapter (for example: [1, 2, 17, 18]). *Under no circumstances should equation 4-3 be used in assessment studies before carefully reading these references.*

The USLE Data Base: The data base for the USLE has been reduced to a series of maps, nomographs, and tables. These data are reproduced in subsequent sections for easy reference. A more detailed description of each factor is given below to aid in parameter selection.

R - The rainfall factor is included in equation (4-3) to represent the influence of precipitation on erosion. R is numerically defined as the number of EI units (erosivity index) for the specified time period. EI is calculated as the product of two rainstorm parameters: kinetic energy of the storm in hundreds of foot-tons per acre times its maximum 30-minute intensity in inches per hour. Data from weather stations having 22 years or longer of recording-raingage records were analyzed to determine the long-term, annual average R values for various locations (15). Results are shown in Figure 4-4. Note that for use in locations within the shaded portions of Figure 4-4 adjustments to accomodate the influence of snowmelt runoff are required. Procedures for correction, along with specific recommendations for certain areas, are available from the Soil Conservation Service Regional Technical Center, Portland, Oregon. The data were further analyzed to determine the yearly distribution of R for each region. Curves for each geographical region have been generated (1, 2). The R value can be estimated by interpolation between isolines of Figure 4-4 or by analysis of local rainfall data. For local data, the kinetic energy can be estimated by the following equation (18):

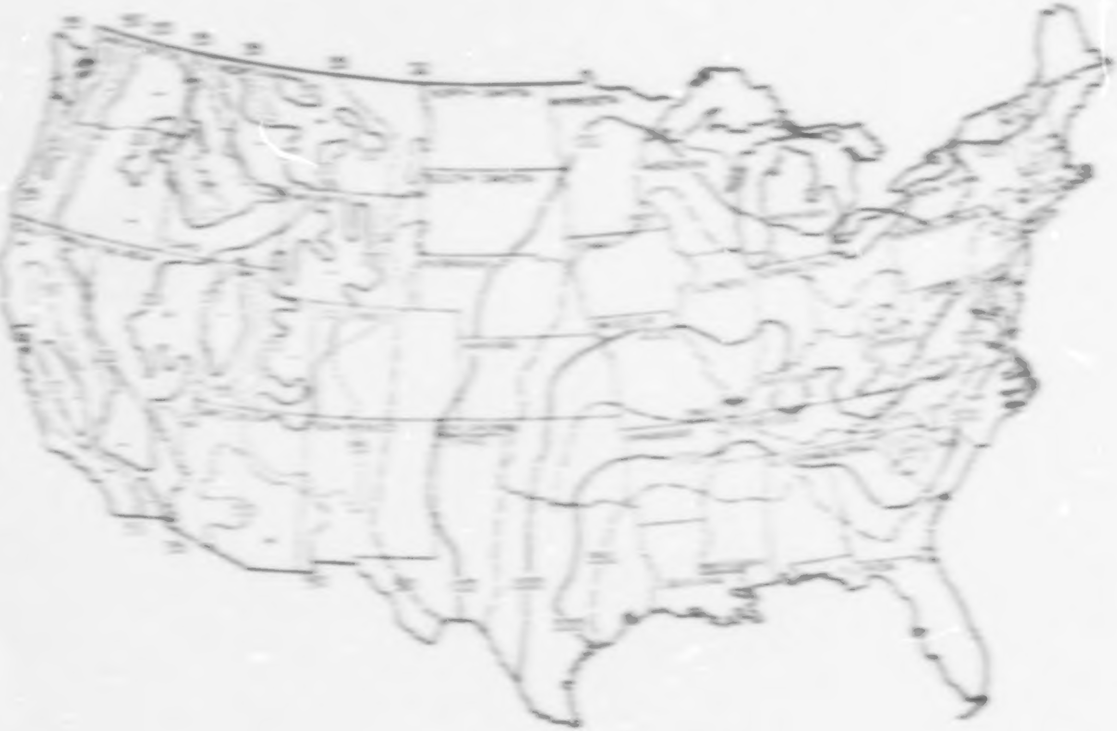
$$E = 916 + 331 \log X \qquad (4-4)$$

where E = kinetic energy, foot-tons/acre
X = rainfall intensity, inches/hour

The product EI is then determined by multiplication of E by the maximum 30-minute rainfall intensity observed for each storm from which X was abstracted.

K - The soil erodability factor reflects soil properties and is a measure of the susceptibility to erosion. Numerical estimates for certain soils were determined by measurements of soil loss per unit of R for a standard set of conditions established on small plots. A generalized procedure for factor estimation was then developed as a function of standard, measurable soil properties. Results are included in Table 4-1 and the nomograph of Figure 4-5. State and local offices of the Soil Conservation Service also have K values tabulated for specific soils and should be consulted for advice.

LS - The steepness and length of slope for a given area impact on erosion rates. The LS factor represents the combined effect of these two variables and numerical estimates have been determined by analysis of experimental data (1). Results are shown by the solid lines in Figure 4-6. Two important features of these data should be noted. First, the data were taken from studies involving slopes with a specific range of steepness and length (refer



REFERENCE: [illegible]

FIGURE 4-4
AVERAGE ANNUAL VALUES OF THE RAINFALL-EROSIVITY FACTOR, R

TABLE 4-17

INDICATIONS OF THE GENERAL MAGNITUDE OF THE SOIL-ERODIBILITY FACTOR, K[a]

Texture Class	Soil Erodibility Factor, K[b] Organic Matter Content 0.05%	2%	4%
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay		0.13-0.29	

[a] Source: (2)

[b] The values shown are estimated averages of broad ranges of specific-soil values. When a texture is near the borderline of two texture classes, use the average of the two K values. For specific soils, use of Figure 4-5 or Soil Conservation Service K-value tables will provide much greater accuracy.

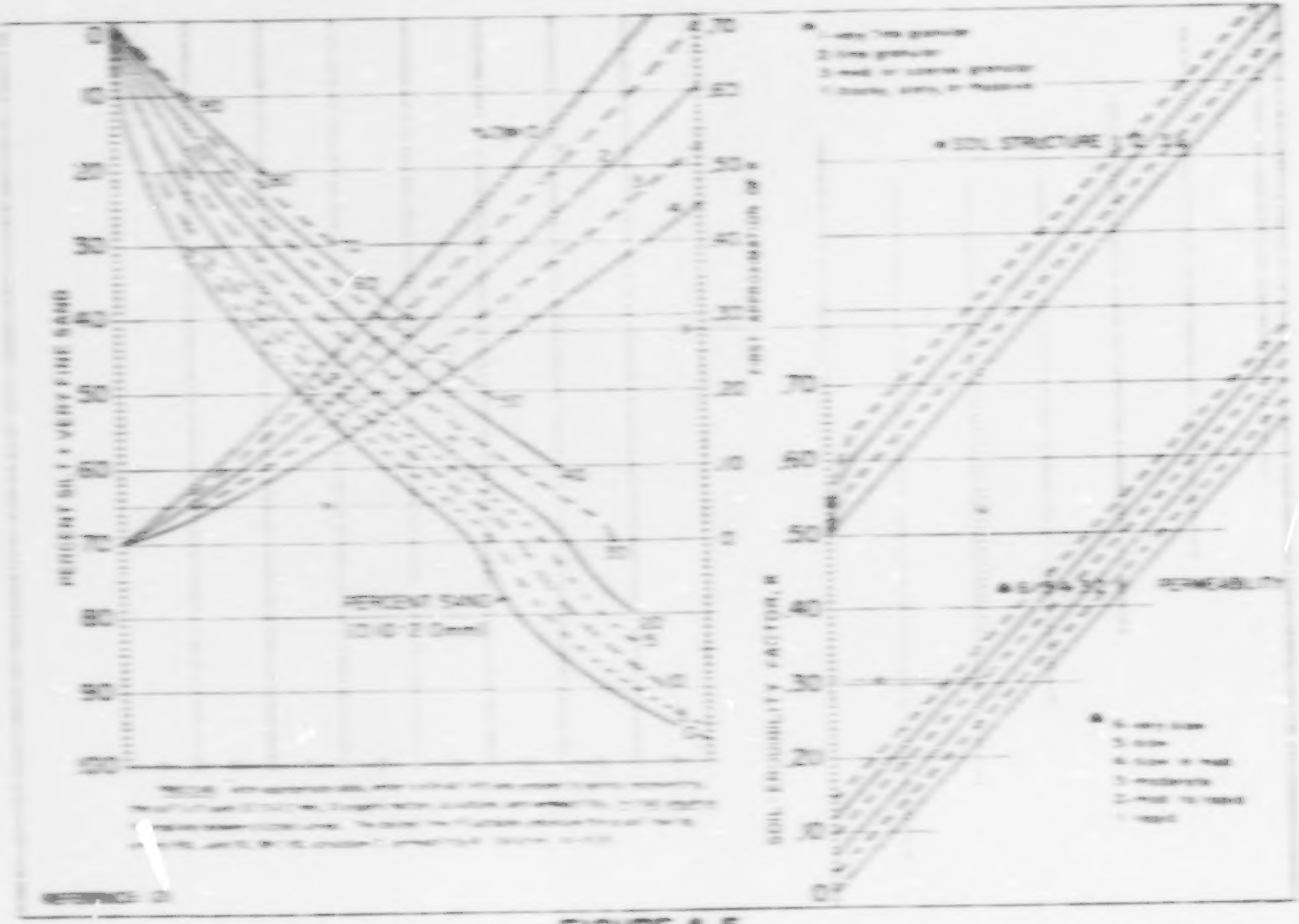
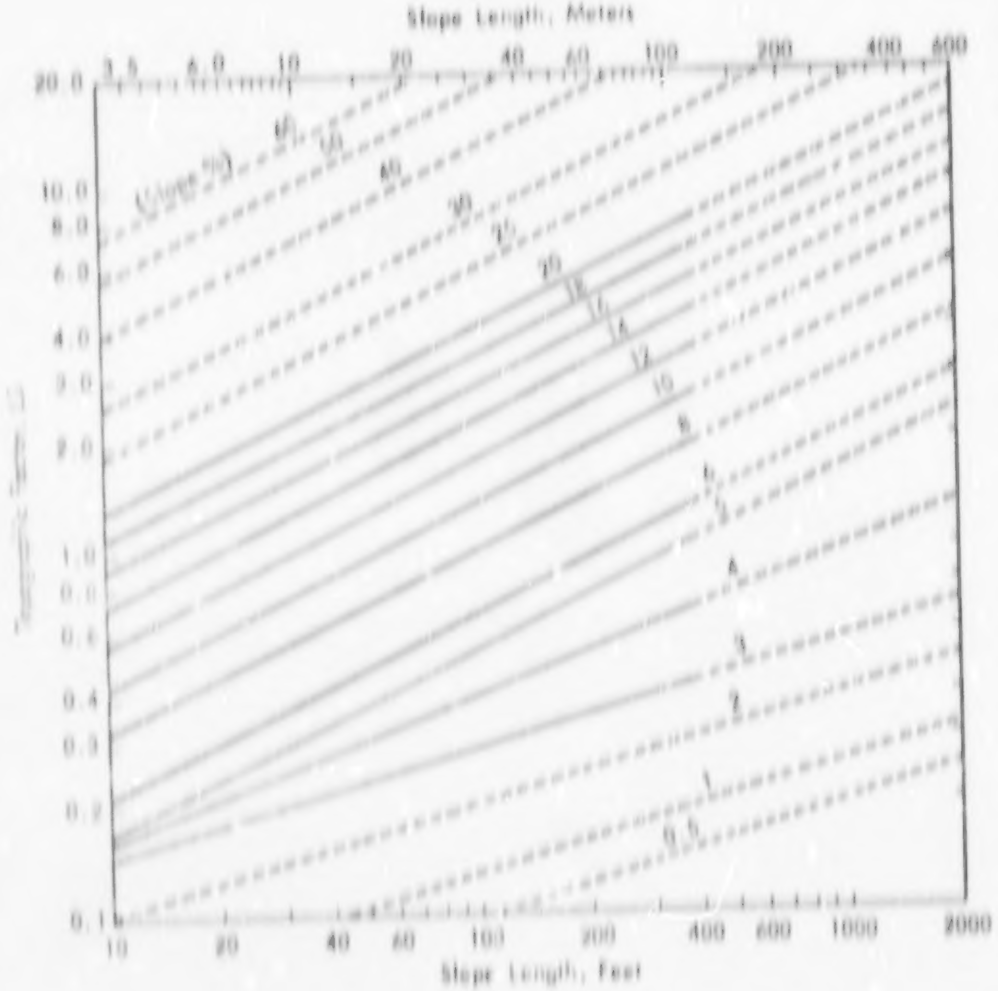


FIGURE 4-5

SOIL-ERODIBILITY FACTOR (K) NOMOGRAPH FOR U.S. MAINLAND SOILS



REFERENCE: (15)

[illegible]

FIGURE 4-6

SAMPLE PLOT OF TOPOGRAPHIC FACTOR (LS) VERSUS SLOPE AND SLOPE LENGTH to note on Figure 4-6). Second, the factors apply to uniform slopes only. Although procedures to correct for the effects of nonuniform slopes have been developed (15), the impact of slope concavity or convexity is not reflected here. The dashed lines of Figure 4-6 represent the extrapolation of the relationship beyond the data base. Validity of this extension is currently unknown.

C - Crop cover and management factors act to mitigate erosion rates. While an annual average C value is often used in the USLE, estimated values, reflecting crop growth stages can also be used. Values range from 0.001 for undisturbed forests to 1.0 for tilled continuous fallow (open, continuously plowed areas). Tables 4-18 through 4-20 summarize appropriate C values for agricultural and silvicultural systems. In cases where the USLE is applied to other land use activities, the C value is approximated by a comparison of the cover conditions to similar cover conditions for agricultural situations. For example, construction activities result in bare, exposed, and disturbed soil surfaces and a C value of 1.0 should be used.

P - Certain other structural or management options related to the landscape serve to mitigate erosion. Such practices are collectively known as supporting practices and include contouring, terracing, strip cropping, etc. The impact of these practices on erosion are estimated through P, with values ranging from 0.25 to 1.0. Table 4-21 summarizes the various P values appropriate for each supporting practice.

4.4.2 A Few Words of Caution

Statistical analyses of the USLE's predictive capability have been performed and a recent paper by the equation's developer summarized these results along with important words of caution for users (17). These precautions are especially noteworthy for those who expand the USLE to aid in estimation of NPS pollutant loads.

The accuracy of the equation was determined by comparing its average annual prediction with measured data from 189 field plots scattered across the country. The overall measured mean soil loss was 11.3 tons per acre. The average prediction error was 1.4 tons with 84% of the predictions within 2

TABLE 4-18

GENERALIZED VALUES OF THE COVER AND MANAGEMENT FACTOR, C, IN THE 37 STATES EAST OF THE ROCKY MOUNTAINS[a,b]

Line number	Crop, rotation, and management[d]	Productivity level[c] High	Productivity level[c] Moderate
		C value	C value
	Base value: continuous fallow, tilled up and down slope	1.00	1.00
Corn			
1	C, RdR, fall TP, conv (1)	0.54	0.62
2	C, RdR, spring TP, conv (1)	0.50	0.59
3	C, RdL, fall TP, conv (1)	0.42	0.52
4	C, RdR, wc seeding, spring TP, conv (1)	0.40	0.49
5	C, RdL, standing, spring TP, conv (1)	0.38	0.48
6	C, fall shred stalks, spring TP, conv (1)	0.35	0.44
7	C(silage)-W(RdL, fall TP) (2)	0.31	0.35
8	C, RdL, fall chisel, spring disk, 40-30% rc (1)	0.24	0.30
9	C(silage, W wc seeding, no-till pl in c-k W (1)	0.20	0.24
10	C(RdL)-W(RdL, spring TP) (2)	0.20	0.28
11	C, fall shred stalks, chisel pl, 40-30% rc (1)	0.19	0.26
12	C-C-C-W-M, RdL, TP for C, disk for W (5)	0.17	0.23
13	C, RdL, strip till row zones, 55-40% rc (1)	0.16	0.24
14	C-C-C-W-M-M, RdL, TP for C, disk for W (6)	0.14	0.20
15	C-C-W-M, RdL, TP for C, disk for W (4)	0.12	0.17
16	C, fall shred, no-till pl, 70-50% rc (1)	0.11	0.18
17	C-C-W-M-M, RdL, TP for C, disk for W (5)	0.087	0.14
18	C-C-C-W-M, RdL, no-till pl 2d & 3rd C (5)	0.076	0.13
19	C-C-W-M, RdL, no-till pl 2d C (4)	0.068	0.11
20	C, no-till pl in c-k wheat, 90-70% rc (1)	0.062	0.14
21	C-C-W-M-M, no-till pl 2d & 3rd C (6)	0.061	0.11
22	C-W-M, RdL, TP for C, disk for W (3)	0.055	0.095
23	C-C-W-M-M, RdL, no-till pl 2d C (5)	0.051	0.094
24	C-W-M-M, RdL, TP for C, disk for W (4)	0.039	0.074
25	C-W-M-M-M, RdL, TP for C, disk for W (5)	0.032	0.061
26	C, no-till pl in c-k sod, 95-80% rc (1)	0.017	0.055
Cotton[e]			
27	Cot, conv (Western Plains) (1)	0.42	0.49
28	Cot, conv (South) (1)	0.34	0.40
Meadow			
29	Grass & Legume mix	0.004	0.01
30	Alfalfa, lespedeza or Sericia	0.020	
31	Sweet clover	0.025	

TABLE 4-15
(Continued)

Line number	Crop, Rotation, and Management[d]	Productivity level[c]	
		High	Moderate
		C Value	
Base value:	continuous fallow, tilled up and down slope	1.00	1.00
Sorghum, Grain (Western Plains)			
32	RdL, spring TP, conv (1)	0.43	0.53
33	No-till pl in shredded 70-50% rc	0.11	0.18
Soybeans			
34	B, RdL, spring TP, conv (1)	0.48	0.54
35	C-B, TP annually, conv (2)	0.43	0.51
36	B, no-till pl	0.22	0.28
37	C-B, no-till pl, fall shred C stalks (2)	0.18	0.22
Wheat			
38	W-F, fall TP after W (2)	0.38	
39	W-F, stubble mulch, 500 lbs rc (2)	0.32	
40	W-F, stubble mulch, 1000 lbs rc (2)	0.21	
41	Spring W, RdL, Sept TP, conv (N & S Dak) (1)	0.23	
42	Winter W, RdL, Aug TP, conv (Kans) (1)	0.19	
43	Spring W, stubble mulch, 750 lbs rc (1)	0.15	
44	Spring W, stubble mulch, 1250 lbs rc (1)	0.12	
45	Winter W, stubble mulch, 750 lbs rc (1)	0.11	
46	Winter W, stubble mulch, 1250 lbs rc (1)	0.10	
47	W-M, conv (2)	0.054	
48	W-M-M, conv (3)	0.026	
49	W-M-M-M, conv (4)	0.021	

[a] Source: (2)

[b] This table is for illustrative purposes only and is not a complete list of cropping systems or potential practices. Values of C differ with rainfall pattern and planting dates. These generalized values show approximately the relative erosion-reducing effectiveness of various crop systems, but locationally derived C values should be used for conservation planning at the field level. Tables of local values are available from the Soil Conservation Service.

[c] High level is exemplified by long-term yield averages greater than 75 bu. corn or 3 tons grass-and-legume hay; or cotton management that regularly provides good stands and growth.

[d] Numbers in parentheses indicate number of years in the rotation cycle. Number (1) designates a continuous one-crop system.

TABLE 4-18
(continued)

[e] Grain sorghum soybeans, or cotton may be substituted for corn in lines 12, 14, 15, 17-19, 21-25, to estimate C values for sod-based rotations.

Abbreviations defined:

B = soybeans
C = corn
c-k = chemically killed
conv = conventional
cot = cotton
F = fallow
M = grass & legume hay
pl = plant
W = wheat
wc = winter cover

lbs rc = pounds of crop residue per acre remaining on surface after new crop seeding
% rc = percentage of soil surface covered by residue mulch after new crop seeding
70-50% rc = 70% cover for C values in first column; 50% for second column
RdR = residues (corn stover, straw, etc) removed or burned
RdL = all residues left on field (on surface or incorporated)
TP = turn plowed (upper 5 or more inches of soil inverted, covering residues)

TABLE 4-19

C FACTORS FOR PASTURE, RANGELAND, AND IDLE LAND[a,b]

Vegetative Canopy Type and Height of Raised Canopy[c]	Canopy Cover,[d] %	Type[e]	Cover that Contacts the Surface					
			Percent Ground Cover					
			0	20	40	60	80	95-100
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	0.45	0.24	0.15	0.090	0.043	0.011
Canopy of tall weeds or short brush (0.5 m fall height)	25	G	0.36	0.17	0.09	0.038	0.012	0.003
		W	0.36	0.20	0.13	0.082	0.041	0.011
	50	G	0.26	0.13	0.07	0.035	0.012	0.003
		W	0.26	0.16	0.11	0.075	0.039	0.011
	75	G	0.17	0.10	0.06	0.031	0.011	0.003
		W	0.17	0.12	0.09	0.067	0.038	0.011
Appreciable brush or bushes (2 m fall height)	25	G	0.40	0.18	0.09	0.040	0.013	0.003
		W	0.40	0.22	0.14	0.085	0.042	0.011
	50	G	0.34	0.16	0.085	0.038	0.012	0.003
		W	0.34	0.19	0.13	0.081	0.041	0.011
	75	G	0.28	0.14	0.08	0.036	0.012	0.003
		W	0.28	0.17	0.12	0.077	0.040	0.011
Trees but no appreciable low brush (4 m fall height)	25	G	0.42	0.19	0.10	0.041	0.013	0.003
		W	0.42	0.23	0.14	0.087	0.042	0.011
	50	G	0.39	0.18	0.09	0.040	0.013	0.003
		W	0.39	0.21	0.14	0.085	0.042	0.011
	75	G	0.36	0.17	0.09	0.039	0.012	0.003
		W	0.36	0.20	0.13	0.083	0.041	0.011

[a] Source: (15)

[b] All values shown assume: 1) random distribution of mulch or vegetation, and 2) mulch of appreciable depth where it exists.

[c] Average fall height of waterdrops from canopy to soil surface, m = meters.

[d] Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).

[e] G = Cover at surface is grass, grass-like plants, decaying compacted duff, or litter at least 5 cm (2 in.) deep.
W = Cover at surface is mostly broadleaf herbaceous plants (as weeds) with little lateral-root network near the surface and/or undecayed residue.

TABLE 4-20

C FACTORS FOR WOODLAND[a]

Stand Condition	Tree Canopy[b] Percent of Area	Forest Litter[c] Percent of Area	Undergrowth[d]	C Factor
Well stocked	100-75	100-90	Managed[e]	0.001
			Unmanaged[e]	0.003-0.011
Medium stocked	70-40	85-75	Managed	0.002-0.004
			Unmanaged	0.01-0.04
Poorly stocked	35-20	70-40	Managed	0.003-0.009
			Unmanaged[f]	0.02-0.09

[a] Source: [15]

[b] When tree canopy is less than 20%, the area will be considered as grassland or cropland for estimating soil loss.

[c] Forest litter is assumed to be at least 2 inches deep over the percent ground surface area covered.

[d] Undergrowth is defined as shrubs, weeds, grasses, vines, etc., on the surface area not protected by forest litter. Usually found under canopy openings.

[e] Managed = grazing and fires are controlled.
Unmanaged = stands that are overgrazed or subjected to repeated burning.

[f] For unmanaged woodland with litter cover of less than 75%, C values should be derived by taking 0.7 of the appropriate values in Table 4-19. The factor of 0.7 adjusts for the much higher soil organic matter on permanent woodland.

TABLE 4-21

P VALUES FOR EROSION CONTROL PRACTICES ON CROPLANDS[a]

Range of Slope	Erosion Control Practice				
	Up and Down Hill	Cross-Slope Farming Without Strips	Contour Farming	Cross-Slope Farming With Strips	Contour Strip-Cropping
2.0-7	1.0	0.75	0.50	0.37	0.25
7.1-12	1.0	0.80	0.60	0.45	0.30
12.1-18	1.0	0.90	0.80	0.60	0.40
18.1-24	1.0	0.95	0.90	0.67	0.45

[a] Source: (1)

tons of the measured losses. Further analysis also showed that larger errors were associated with measured data collected over shorter time periods than the 22-year cycle chosen for the R data base.

Considerable error can result if the equation factors are estimated incorrectly for large areas where watershed sediment yield is the objective. The author states..."Applying the equation to a complex watershed by using overall averages of slope length and gradient with estimated watershed-average value for factors K and C would be incorrect. To use the equation correctly, the combination of selected factor values must reflect the manner in which the parameters are associated in each subarea....Perhaps the greatest potential source of prediction error is superficiality in selecting factor values....If the selected values do not truly represent the conditions to be evaluated, neither will the computed soil loss." (17).

4.4.3 Sediment Delivered to the Stream

Gross erosion as predicted by the USLE suffers the same limitation as pollutant loss data collected at the outlet of plots or small fields - the load to the stream is significantly less than these values because other components of the hydrologic system act to attenuate their magnitude. For sediment, this attenuation is a function of many variables including soil characteristics, watershed area, slopes, slope length, relief/length ratio, and drainage density. Erosion from gullies or the stream channel itself is a contributor to downstream sediment load but is not included in the USLE predictions.

Correction for the efficiency of a watershed system to yield eroded sediments to a point downstream is made by application of a sediment delivery ratio (SDR). The SDR is defined as the ratio of sediment delivered at a location in the stream system to the gross erosion from the drainage area above that point.

Ideally, one could structure a model using sediment transport theory and route both water and sediment through the system. Failing that, most investigators have chosen to develop empirical relationships (based on data) for sediment delivery including one or more of the variables listed above. The results of a recent development for use with NPS loading functions are given in Figure 4-7. Drainage density in Figure 4-7 is defined as the ratio of total channel-

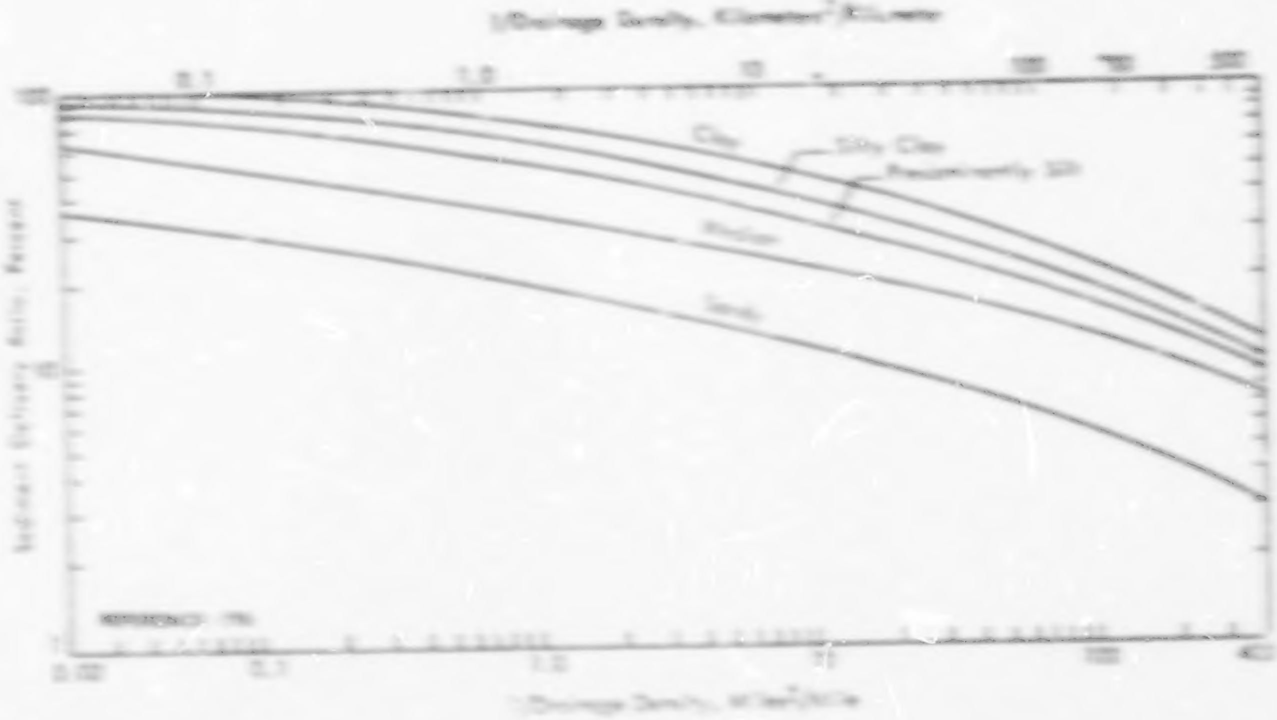


FIGURE 4-7
SEDIMENT DELIVERY RATIO FOR RELATIVELY HOMOGENEOUS BASINS

segment lengths to the basin area. Note also the different relationship for each soil particle size class. This distinction is made to accommodate the greater ease with which finer materials are transported.

Application of the SDR to the USLE enables the analyst to estimate loads to a specific point in the stream. A sediment yield equation is thus given by:

$$Y(S)_E = A(RKLSCP)S_d \tag{4-5}$$

where $Y(S)_E$ = sediment loading to stream, tons/yr
A = area, ac
$RKLSCP$ = factors of USLE
S_d = sediment delivery ratio

If data are available for the area of interest, S_d should be validated, if possible, by analysis of the data. Usually, reservoir sedimentation rates are the most commonly available data sources.

4.4.4 A Few More Words of Caution

The USLE does not estimate erosion from gullies, stream banks, or head cuts. Delivery ratios based on locally measured data may include the lumped effects of these sources as well as the sources estimated by the USLE. The most appropriate value is given by:

$$S_d = \frac{SY}{SH + GU + CH} \tag{4-6}$$

where SY = sediment yield at point of interest
SH = USLE related erosion
GU = gully erosion
CH = channel erosion

Note that if S_d is determined from measured data that accounts for only SH in the denominator of equation 4-6, the resulting ratio will be too high when applied to new values of SH for prediction of SY. To illustrate this possible source of error, data from a recent paper on sediment yield from two watersheds in the Mississippi Delta were analyzed (19). The study reported estimates of each source of erosion (sheet, gully, and channel) and the total watershed sediment yield. Calculated 15-year mean sediment delivery ratios were 0.28 and 0.57, respectively. Calculation of similar values, but based on estimates for sheet erosion only (per USLE), yielded ratios of 0.42 and 0.80, respectively. Use of these uncorrected delivery ratios in NPS assessment studies would result in the estimated values being 150% and 140% of the actual loads.

4.4.5 MRI Loading Functions

The final step in developing a series of pollutant loading functions based on sediment delivered to the stream is correlation of pollutants to sediments. Two options are available. A direct ratio of pollutants to sediment can be determined by field sampling followed by calibration of equation (4-5). A similar procedure is recommended for models like the NPS (20) and STORM (21). The other option is a correlation between pollutants and *in situ* soil along with a factor to correct for the enrichment process discussed in section 4.3.3. Midwest Research Institute (15) used this approach and developed a series of loading functions having the form:

$$Y(P)_E = aY(S)_E \, C_s(P) r_p \qquad (4\text{-}7)$$

where $Y(P)_E$ = pollutant, P, load to streams

a = dimensional constant

$Y(S)_E$ = sediment loading to stream (using equation (4-5))

$C_s(P)$ = concentration of pollutant, P, in soil profile

r_p = enrichment ratio for pollutant, P

The enrichment ratio, r_p, corrects for the observed phenomena that pollutants in eroded sediments are somewhat more concentrated than the same pollutants in the watershed soil profile. Numerical values are simply the ratio of the two concentrations. The need for such a ratio is not surprising in view of the surface area differences among soil fractions. That is, the much greater surface area associated with the finer, more erodable particles (see equation (4-1).)

Equation(4-7)is further modified for certain pollutants to account for the "unavailability" of portions of the load. For example, if equation(4-7)were used to estimate only total phosphorus loadings, determining the water quality impact would be difficult because it is only the biologically available phosphorus that exerts the impact. This correction is made by simply multiplying equation (4-7) by an availability factor (percent of load that is immediately available for use by plants or animals).

A summary of the MRI loading functions is given in Tables 4-22 and 4-23. Details of their development and additional information is included in the EPA report entitled "Loading Functions for Assessment of Water Pollution From Nonpoint Sources," EPA-600/2-76-151, (May 1976).

The most accurate results from equation (4-7) can be expected when the long-term average annual loads are estimated. The temporal distribution of the annual loads is important in water quality impacts, however, especially for those pollutants exerting short-term impacts. To accommodate the necessity to estimate peak loads over a one-year period, two methods are proposed.
First, if one assumes that the only variation in the USLE factors for a given area is that attributed to rainfall, then, it is possible to distribute the loads according to the distribution of R. That is, all factors in the USLE are considered fixed except for R. The variation in R is determined by cumulative distribution curves developed by the Soil Conservation Service (1) and reproduced by MRI (15). Figure 4-8 generated (15) from the cumulative distribution curves, is expressed in units of percent of gross surface erosion expressed on a daily basis. The percent of the annual erosion for each time period is easily determined by multiplying each data point (for each month) by the number of days in the month. The shape of the curve will obviously remain the same.

The assumption that all factors of the USLE will remain the same throughout the year is unlikely for land uses subject to operations like agriculture. For these situations, the curve is further modified by the C factor. Periods for which the C factors are different are determined and the product RC is used to distribute the loads. Results for continuous corn in central Indiana is given in Figure 4-9. Note the synergistic effects of both the high R values and high C values for the mid-June to mid-July period resulting in maximum loadings for the year.

The MRI Loading Functions Data Base: The MRI document repeatedly stresses the value of obtaining locally derived data inputs from knowledgeable sources. This advice is indeed appropriate and typical sources are listed in Appendix C as well as the MRI report (15). In cases where local data are

TABLE 4-22

LOADING FUNCTIONS SUMMARY[a]

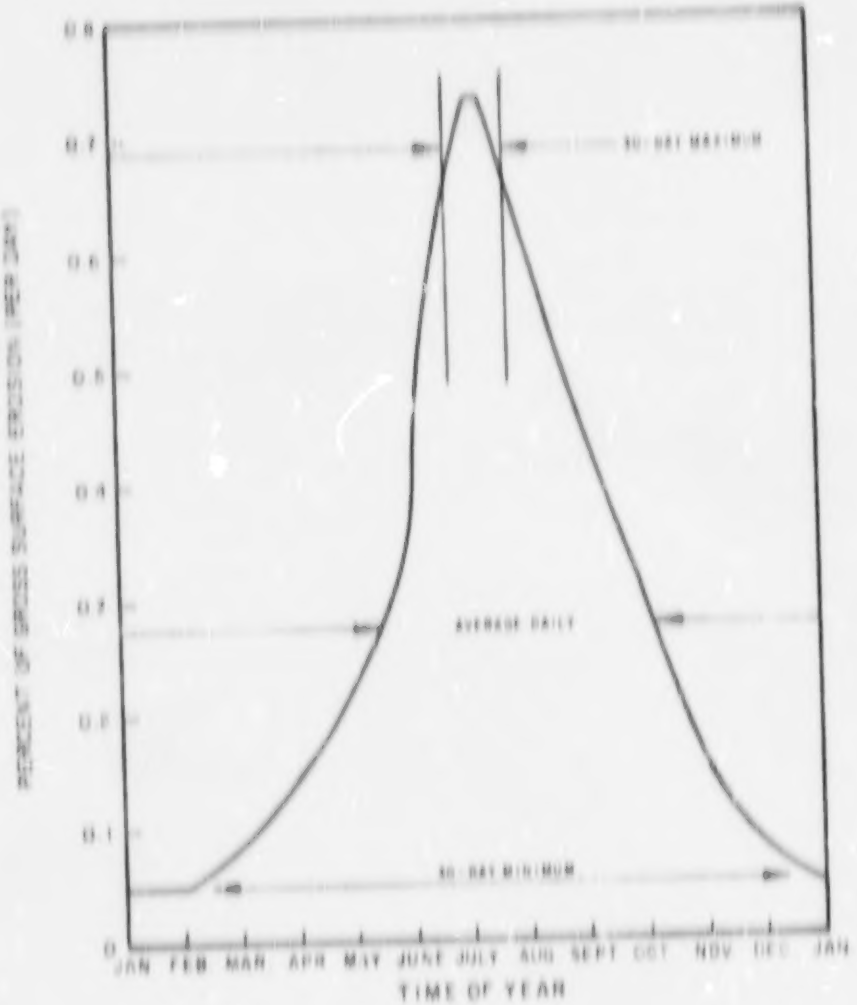
Loading Type or Source	Loading Function	Description
Sediment: Agricultural	[illegible]	[illegible]
Nitrogen	[illegible]	[illegible]
Phosphorus	[illegible]	[illegible]
Organic Matter	[illegible]	[illegible]
Pesticides, Herbicides, Insecticides, Fungicides	[illegible]	[illegible]
Salinity	[illegible]	[illegible]
Sediment: 1) Agriculture 2) Construction 3) Surface Mining	[illegible]	[illegible]
Acid Mine Drainage	[illegible]	[illegible]
Heavy Metals	[illegible]	[illegible]
Feedlots	[illegible]	[illegible]
Terrestrial Disposal	[illegible]	[illegible]

[a] These loading functions are derived and explained by [illegible] in Reference [15]

TABLE 4-23

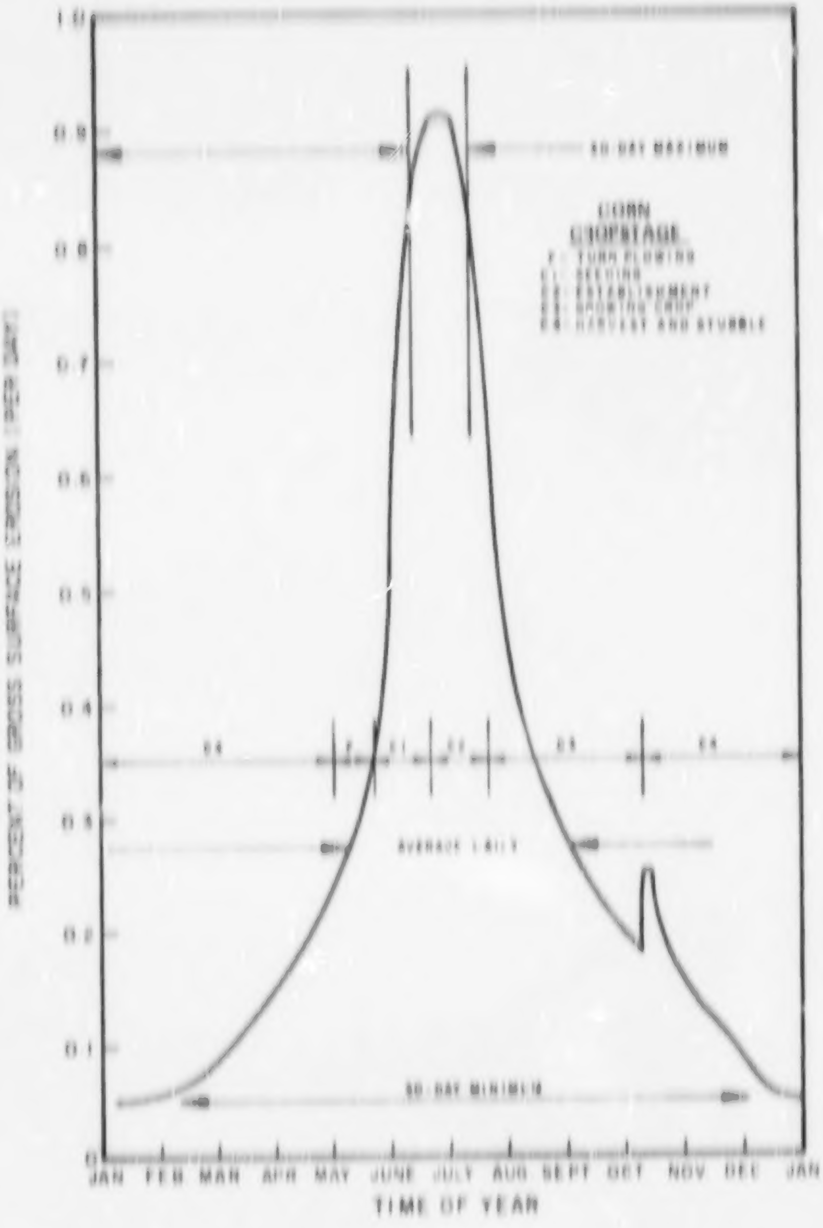
LIST OF SYMBOLS USED IN TABLE 4-22

[illegible]



REFERENCE: (15)

FIGURE 4-8
PROJECTED VARIATION OF SOIL EROSION



REFERENCE: (15)

FIGURE 4-9
PROJECTED VARIATION OF SOIL EROSION

unavailable or where only a first-cut analysis is desired, procedures are proposed for parameter estimation. Factors associated with sediment loading were discussed in sections 4.4.1, 4.4.2, and 4.4.3. The following data apply to the pollutant associated parameters of selected loading functions.

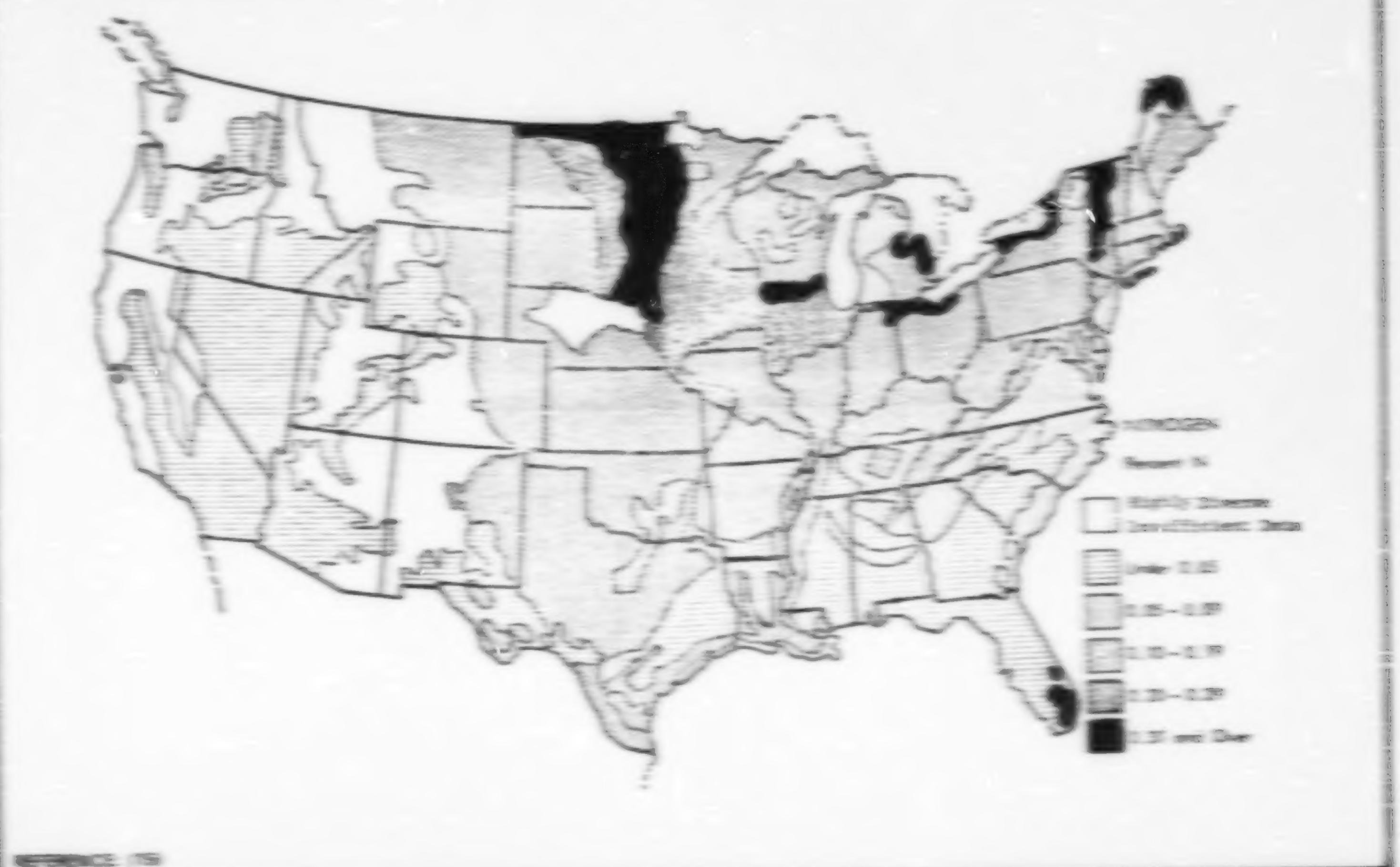
Soil-Pollutant Concentrations - Cs(P) of equation (4-7) - Soil sampling data is the most reliable and current data available for estimation of Cs(P). Failing that, however, one can use the maps given in Figures 4-10 and 4-11 for soil nitrogen and phosphorus content. Organic matter estimates are made by multiplying the nitrogen values by 20. An alternative method for estimating nitrogen concentrations is also included in the MRI document (15) but will not be repeated here.

Enrichment Ratios - (r_p in equation(4-7))- Estimation of enrichment ratios without the benefit of locally derived data requires extrapolation at its best (or worst). Only a few experimental studies have reported measured values and no theoretical approaches to prediction have been attempted. Table 4-24 gives typical values for nitrogen and phosphorus. MRI used values of 2.0 and 1.5 for nitrogen and phosphorus, respectively, in solution of example problems. No experimentally determined values for organic matter are reported, but MRI suggested a range of from 1.0 to 5.0 and used a value of 2.5 for the completed example.

Availability Factors - The fraction of total pollutants that are available for immediate use by aquatic plants, etc., is also difficult to estimate with certainty. For nitrogen, MRI suggested an upper limit of 15%, reported a value of 8% and used 6% in their completed example. For phosphorus, values of 5% and 10% were reported and 10% was chosen for use in their completed example. No availability factors were given for organic matter, but the fraction of organic matter exerting BOD is important from a water quality impact perspective. Locally determined BOD values for surface soil organic matter should provide useful information.

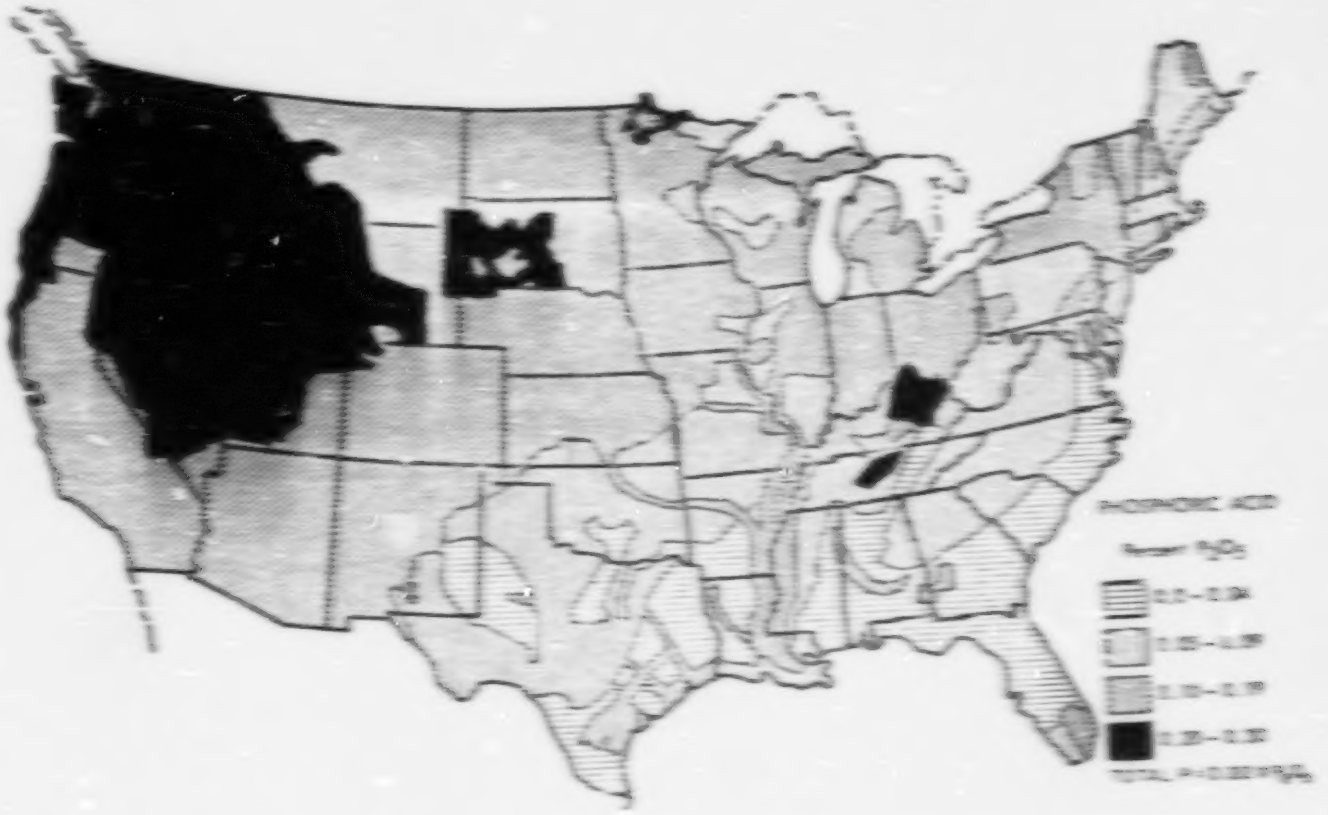
4.5 Methodology for Preliminary Assessment of Nonurban Nonpoint Source Loadings

The techniques and data bases discussed in the previous sections can be used to assess the nature, magnitude, and extent of nonpoint source pollutant



REFERENCE: 176

FIGURE 4-10
PERCENT NITROGEN (N) IN SURFACE FOOT OF SOIL



REFERENCE: (15)

FIGURE 4-11

PERCENT PHOSPHORUS (P) IN SURFACE FOOT OF SOIL

TABLE 4-24

SUMMARY OF EXPERIMENTALLY DETERMINED ENRICHMENT RATIOS[a]

Land use	Ratio	
	Nitrogen	Phosphorus
Fallow	3.88	1.59
Rye winter cover crop	4.08	1.56
Manure spreading	4.28 3.35	1.47 1.47
Agricultural[b]	2.0 2.7	- -

[a] Source: (15)

[b] No specific activity reported.

loading. Assessment can be preliminary or comprehensive, depending on the choice of the methodology and the resources available for analysis. Whatever the approach taken, interpretation of the data base (both measured and abstracted from previous studies), and loading predictions should only be made with due consideration for the hydrologic-watershed system described in section 4.2.2.

The approach chosen for presentation in the following sections can result in at best a preliminary assessment and was designed to be consistent with the analysis for urban loadings presented in Chapter 3. The general approach, however, is useful as a guide for assessment regardless of the particular set of tools (models) chosen for use. The methodology is limited to a problem assessment only - evaluation of alternative control strategies, selection of controls, and economic analyses are not included.

4.5.1 Statement of the Problem and the Solution Methodology

The Problem: As part of a water quality impact assessment study in a planning area, a specific (typical) watershed is chosen to evaluate the nature, extent, and magnitude of NPS loads. Subsequently, an analysis of the water quality impacts for the water quality limited stream segment into which the watershed drains will be made. The pollutant types, magnitude, and timing are desired.

The Methodology: The assessment procedure has been divided into six steps, as shown in Figure 4-12. Each step consists of an activity requiring input information of the type described. Completion of the activity results in a series of outputs that are, in turn, available for inputs to the next step or for decision-making. For steps II, III, IV, and VI, references to previous sections are given to indicate the location of necessary or useful information. To illustrate the methodology each step in Figure 4-12 will be completed for a hypothetical example consistent with the problem stated above. Data for step I will be abstracted from a report by the Ohio River Basin Sanitation Commission (Reference: 22). Steps II through VI will be completed using information contained in previous sections of this chapter and certain other assumptions (hopefully reasonable) that are necessary to complete the example.

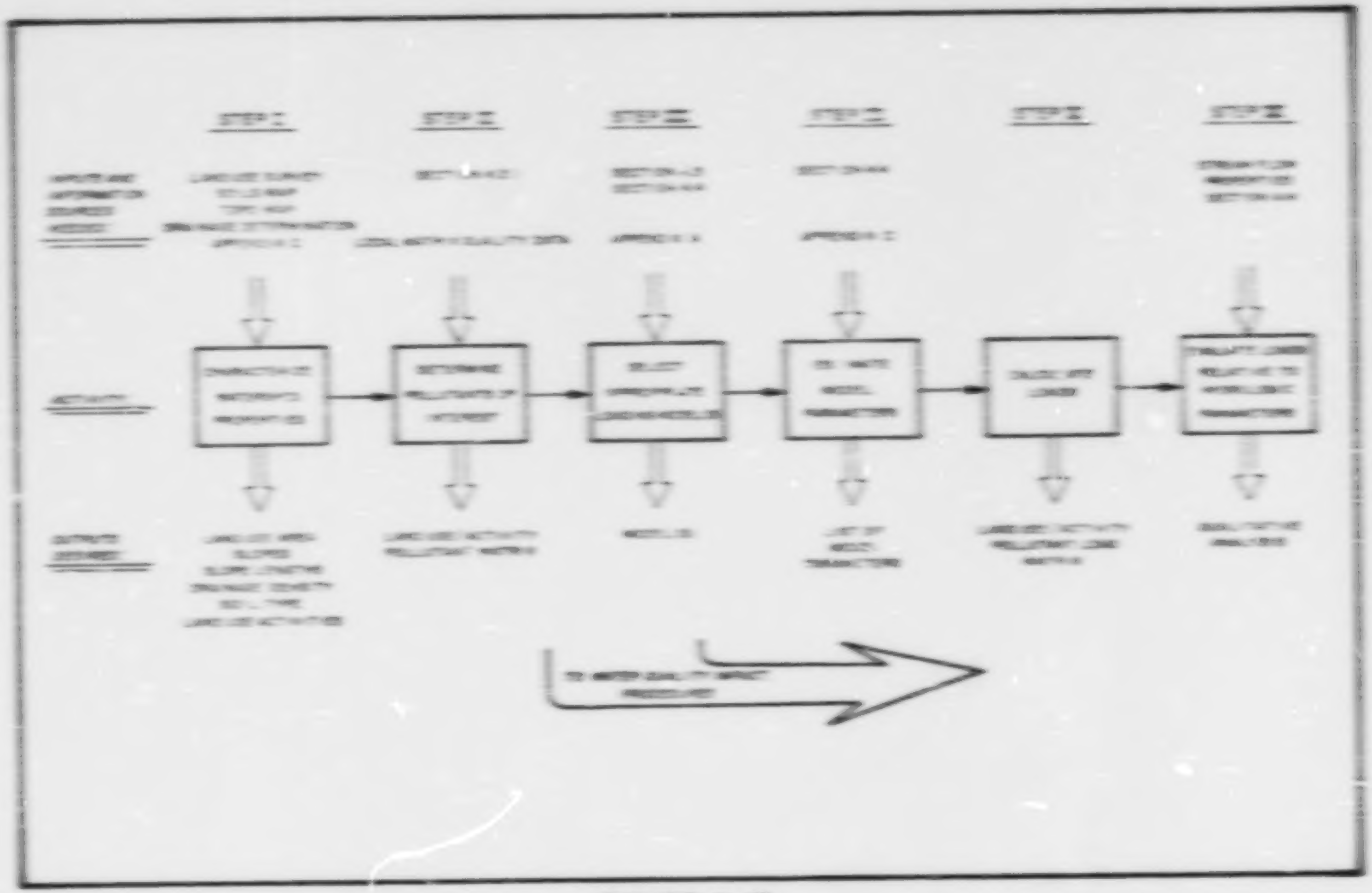


FIGURE 4-12

SCHEMATIC REPRESENTATION OF NPS LOAD ASSESSMENT METHODOLOGY

4.5.2 Example Case Study

The methodology shown in Figure 4-12 will now be illustrated such that the "problem" defined above can be solved. Each step will be considered separately.

Step I: The study area chosen is a hypothetical watershed located in central Indiana, cleverly referred to as Indiana Creek Watershed. A schematic of the watershed, complete with land uses noted, is given in Figure 4-13. Vital statistics were obtained from the county and state Soil Conservation Service, a recent land use survey, and standard USGS topographical maps. Analysis of these data resulted in Table 4-25. Note that the slopes and soil types are amazingly uniform.

Step II: The objective of step II is a listing of the potential pollutants arising from the land uses and land use activities on the watershed. From Tables 4-1 through 4-7, a new matrix was developed for Indiana Creek as shown in Table 4-26. Additional information from water quality surveys suggests nutrients and organics (BOD_5) are the most serious problems.

Step III: Normally, specific loading models should only be selected after careful consideration of the known water quality problems, analysis of the available resources, and the importance (economic or political) of the decision to be made with the resulting information. Such an effort should never be taken lightly. Fortunately, the task in this case is straightforward. Loading functions developed by MRI which are based on equation (4-5) will be used. Utilization of this approach permits desk-top calculations. Equations for each pollutant of interest in Table 4-26 are listed below.

Sediment, tons/year

$$Y(S)_E = \sum_{i=1}^{3} A_i (RKLSCP)_i \, S_d \qquad (4\text{-}8)$$

Total Nitrogen, pounds/year

$$Y(NT) = \sum_{i=1}^{3} a \cdot Y(S)_{E_i} \, C_s(NT)_i \, r_N \qquad (4\text{-}9)$$

Available nitrogen, pounds/year

$$Y(NA) = f_N \, Y(NT) \qquad (4\text{-}10)$$

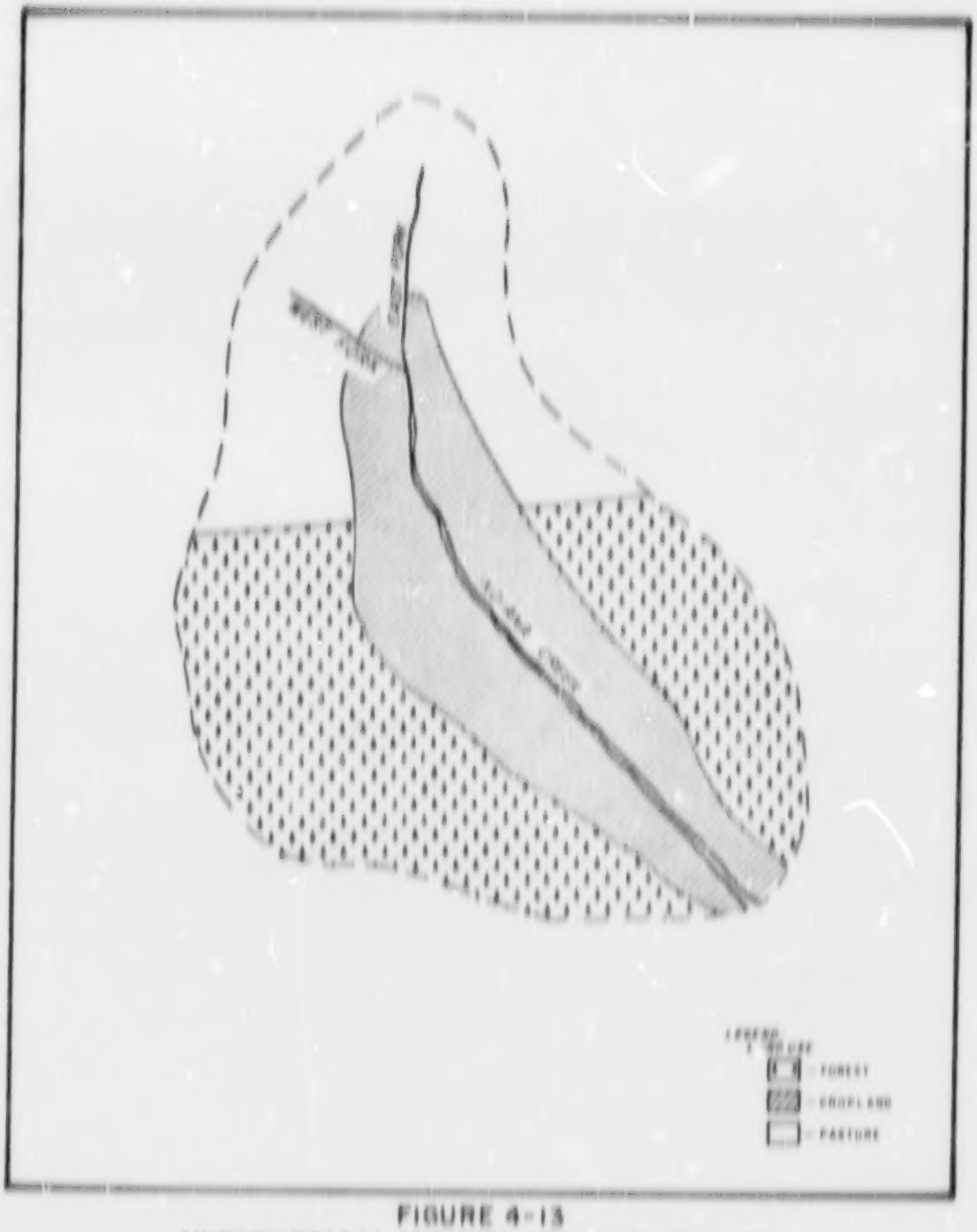


FIGURE 4-13
HYPOTHETICAL INDIANA CREEK WATERSHED

TABLE 4-25

SUMMARY OF INDIANA CREEK WATERSHED PROPERTIES

Watershed Properties	Land Use Cropland	 Forest	 Pasture	Totals
Area, ac	280	450	270	1000
Predominant slopes, %	6	15	8	-
Predominant slope length, ft	300	120	200	-
Soil type	Fayette silt loam, 4% organic matter	Silt loam	Fayette silt loam, 4% organic matter	-
Total stream segment length, mi	-	-	-	1.0
Land use activities	Continuous corn, contour plowing, conventional tillage, yield 80-90 bu/ac, residue left	Medium stocked, 50% tree canopy cover, 80% litter cover, managed undergrowth	80% ground cover	

TABLE 4-26

SUMMARY OF POTENTIAL POLLUTANTS IN INDIANA CREEK DRAINAGE

Land Use Activity	Potential Pollutants Sediment	 Nitrogen	 Phosphorus	 Organics (BOD_5)	 Pesticides
Cropland	X	X	X	X	X
Pasture	X	X	X	X	
Forests	X	X	X	X	

Total phosphorus, pounds/year

$$Y(PT) = \sum_{i=1}^{3} a \cdot Y(S)_{E_i} \, C_s(PT)_i \, r_P \qquad (4\text{-}11)$$

Available phosphorus, pounds/year

$$Y(PA) = f_P \, Y(PT) \qquad (4\text{-}12)$$

Organic matter, pounds/year

$$Y(OM) = \sum_{i=1}^{3} a \cdot Y(S)_{E_i} \, C_s(OM)_i \, r_{OM} \qquad (4\text{-}13)$$

BOD_5, pounds/year

$$Y(BOD_5) = f_B \, Y(OM) \qquad (4\text{-}14)$$

where i = land use: cropland = 1, pasture = 2, forest = 3

A = land area for land use i, acres

$RKLSCP$ = factors of USLE, see equation (4-3)

S_d = sediment delivery ratio

f_N, f_P, f_B = availability constants for nitrogen, phosphorus, and organic matter, expressed as fraction of total that is available

r_N, r_P, r_{OM} = enrichment ratios for nitrogen, phosphorus, and organic matter

$C_s(N)$, $C_s(P)$, $C_s(OM)$ = soil profile concentrations of nitrogen, phosphorus, and organic matter, gm/100 gms

a = 20

Of the pollutants listed in Table 4-26 for Indiana Creek, only pesticides were omitted in the above list of loading functions. This in no way implies pesticides are of no real concern and should be omitted. Rather, it reflects current inability to adequately assess pesticides except at a rather detailed level quite beyond the scope of this manual and, in particular, this example. Also, none of the water quality impact analyses given in this manual include pesticides. A more qualitative analysis of the pesticide problem will be given in step VI.

Step IV: Equations (4-8) through (4-14) contain a number of parameters that must be estimated. Some represent properties of the entire watershed while others are land use or pollutant specific. Each set of parameters will be selected based on the material given in previous sections.

Sediment - The sediment delivery ratio is determined from Figure 4-7. Note from Table 4-25 that the watershed has an area of 1000 acres (1.56 square miles) and a stream length of 1.0 miles, yielding a drainage density of 0.64. The inverse drainage density is 1.56. The soil type is silt loam which is predominately silt. The resulting R_d value from Figure 4-7 is 0.50. The R value in equation (4-8) is common to the entire watershed and is estimated to be 175 as interpolated from Figure 4-4. The K value is also assumed constant for the watershed since each land use has the same soil type and from Table 4-17 is estimated to be 0.33.

The remaining sediment-related parameters are land-use specific and are estimated as follows:

Topographic Factors from Figure 4-6:
- Cropland - LS = 1.2
- Pasture - LS = 1.4
- Forest - LS = 2.8

Cover and Management factors, from Tables 4-18, 4-19, 4-20:
- Cropland - C = 0.38
- Pasture - C = 0.013
- Forest - C = 0.003

Erosion Control factors, from Table 4-21:
- Cropland - P = 0.50
- Pasture - P = 1.0
- Forest - P = 1.0

Pollutants - The parameters associated with pollutants other than sediment are included in equations (4-9) through (4-14). Assuming no local soil surveys, appropriate values are abstracted from Figures 4-10 and 4-11, and Tables 4-24 and 4-25.

From Figures 4-10 and 4-11, the concentrations of nitrogen and phosphorus (calculated from $P=0.22 \times P_2O_5$) in the soil are:

$C_s(NT)$ = 0.145% (mid-point of range)
$C_s(PT)$ = 0.032% (mid-point of range)
$C_s(OM)$ = 4.0% (From Table 4-25)

Note that $C_s(OM)$ is based on the given soil characteristics and exceeds the suggested value based on $C_s(NT)$. A value of 20 times $C_s(NT)$, or 2.9, would result from the guidance in section 4.4.5

From section 4.4.5
f_N = 0.06
f_P = 0.10

No guidance was given on the relationship of BOD to organic matter so a value of f_B = 0.06 was arbitrarily chosen.

From section 4.4.5
r_N = 2.0
r_P = 1.5
r_{OM} = 2.5

The summary of the selected model parameters for the Indiana Creek Watershed is given in Table 4-27.

Step V: Calculation of loads require application of the parameters of Table 4-27 to equations (4-8 through 4-14). Calculations by land use are illustrated as follows:

Cropland -

$Y(S)_E$ = $280 \times 175 \times 0.33 \times 1.20 \times 0.38 \times 0.5 \times 0.5$
= 1843 tons/year
= 10,100 pounds/day, sediment

$Y(NT)$ = $20 \times 1843 \times 0.145 \times 2.0$
= 10,689 pounds/year
= 29.3 pounds/day, total nitrogen

$Y(NA)$ = 0.06×29.3
= 1.76 pounds/day, available nitrogen

TABLE 4-27

SUMMARY OF LOADING FUNCTION PARAMETERS FOR INDIANA CREEK WATERSHED

Parameter	Land Use		
	Cropland	Pasture	Forest
S_d	0.5	0.5	0.5
R	175	175	175
K	0.33	0.33	0.33
LS	1.20	1.40	2.80
C	0.38	0.013	0.003
P	0.50	1.0	1.0
C_s(NT)	0.145	0.145	0.145
C_s(P)	0.032	0.032	0.032
C_s(OM)	4.0	4.0	4.0
E_N	2.0	2.0	2.0
E_P	1.5	1.5	1.5
E_{OM}	2.5	2.5	2.5
f_N	0.06	0.06	0.06
f_P	0.10	0.10	0.10
f_H	0.06	0.06	0.06

$Y(PT) = 20 \cdot 1843 \cdot 0.032 \cdot 1.5$
$= 1769$ pounds/year
$= 4.85$ pounds/day, total phosphorus

$Y(PA) = 0.10 \cdot 4.85$
$= 0.49$ pounds/day, available phosphorus

$Y(OM) = 20 \cdot 1843 \cdot 4.0 \cdot 2.5$
$= 368{,}600$ pounds/year
$= 1010$ pounds/day, organic matter

$Y(BOD_5) = 0.06 \cdot 1010$
$= 60.6$ pounds/day, BOD_5

Pastures - Similar calculations for pastures yield:

$Y(S)_E = 777$ pounds/day
$Y(NT) = 2.3$ pounds/day
$Y(NA) = 0.14$ pounds/day
$Y(PT) = 0.4$ pounds/day
$Y(PA) = 0.04$ pounds/day
$Y(OM) = 78$ pounds/day
$Y(BOD_5) = 4.7$ pounds/day

Forests - Finally for forests:

$Y(S)_E = 598$ pounds/day
$Y(NT) = 1.7$ pounds/day
$Y(NA) = 0.1$ pounds/day
$Y(PT) = 0.29$ pounds/day
$Y(PA) = 0.03$ pounds/day
$Y(OM) = 60$ pounds/day
$Y(BOD_5) = 3.6$ pounds/day

A summary of the results of the loading calculations are given in Table 4-28 using the land use-pollutant matrix format.

Step VI: The most meaningful way to predict NPS loads includes prediction of runoff as the transporting medium. The USLE-based loading functions only implicitly include hydrology through the R value. Expansion of the assessment procedure in this chapter to include a quantitative representation of

TABLE 4-28

SUMMARY OF POLLUTANT LOADINGS FOR INDIANA CREEK WATERSHED

Land Use Activity	Pollutants, lb/day						
	Sediment	Nitrogen		Phosphorus		Organic Matter	
		Total	Available	Total	Available	Total	BOD_5
Cropland	10,100	29.3	1.76	4.9	0.49	1010	60.6
Pasture	777	2.3	0.14	0.4	0.04	78	4.7
Forest	598	1.7	0.10	0.3	0.03	60	3.6
Total Loading	11,475	33.3	2.00	5.6	0.56	1148	68.9

the watershed hydrology would require a quantum jump in both effort and sophistication. Such an effort is recommended as a mandatory step in any comprehensive analysis, but is not included here.

A qualitative analysis of the watershed hydrology can be accomplished within the ground rules assumed by this manual and is helpful in evaluating the timing and potential impacts of selected pollutants. Recall from section 4.4.5 that the MRI loading functions can be used to predict the time-distributed load by one of two methods. First, assume all equation factors remain constant except for R and the loads are linearly distributed in time as a function of R. Second, allow the R value to be weighted according to the time-varying cover conditions represented by C. The R-distributed and the RC-distributed curves are given in Figures 4-8 and 4-9, respectively.

The superposition of time-varying land use activities, watershed system inputs, and streamflow characteristics on Figure 4-9 provides a qualitative assessment of the interaction of the major system components including the hydrology. Such an analysis for purposes of general "enlightenment" of planning agency personnel has been proposed (23) and will be included here.

A stream-gaging station downstream of Indiana Creek Watershed was selected to represent the hydrologic characteristics of the area. Long-term flow records were abstracted from published flow data and plotted as the annual average monthly distribution in percent of total annual value as shown by curve Q in Figure 4-14. Curve RC is the same as that of Figure 4-9 but expressed as percent of total annual. That is, each monthly value has been multiplied by the number of days in that month. The Q curve requires some further explanation. If the curve was generated from data taken in Indiana Creek, the response would more directly trace the rainfall events imbedded in the RC curves. Downstream, however, the curves can interact as shown because of the areal variability of rainfall and the extraction of water via evapotranspiration. Plotted beneath the two curves are the time "windows" during which certain land use activities and man-induced inputs to the watershed occur. Only the cropland system is represented because the RC curve was calculated

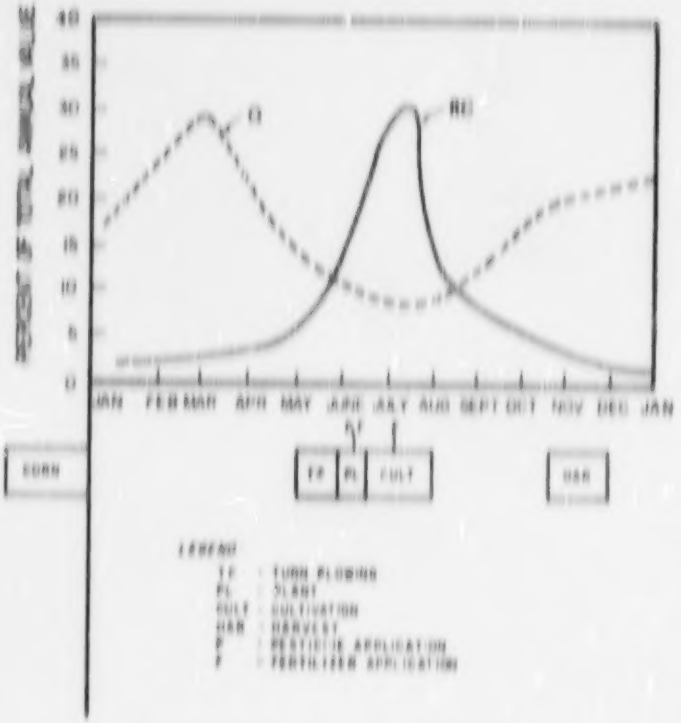


FIGURE 4-14
INTERRELATION OF NON-POINT SOURCE
LAND USE AND HYDROLOGIC TRENDS

using the cropland data. If forestry activities were included a longer time period would be more appropriate.

Note from Figure 4-14 that during the period from May 15 to August 15 several watershed operations occur that can interact to produce nonpoint source loads. The soil surface is essentially bare during a time of highly erosive rainstorms (denoted by RC curve) and relativey low stream flow. Also, the addition of potential pollutants (fertilizers and pesticides) occurs during the same time period. In addition to an evaluation of potential loads, Figure 4-14 suggests time during which field measurements of stream water quality will be most meaningful.

4.6 Specific Nonurban, Nonpoint Source Category Information

As discussed in earlier sections, nonpoint sources of pollutants include nonurban land use activities such as construction, agriculture (including irrigation return flows), silviculture, hydrologic modifications, mining, and residual management practices. In this section of the manual, these specific source categories are discussed individually. The primary intent is to familiarize the planner with the nature of the NPS load-generating potential of each category, the types of pollutants which can be anticipated, and with control measures or management practices which have been identified to be appropriate and which may be considered in the planning process.

The discussion covers each of the categories broadly, and identifies specific documents or publications which may be referred to by the planner to develop the in-depth information and guidance which will be required to address those NPS problems which are important in his planning area.

The primary reference publications for each NPS category include a series of EPA documents, either published or to be released in the near future. These include:

(a) EPA Office of Research & Development Reports - These are guideline manuals which provide technical information relating to specific land use categories or types of activity.

(b) EPA 304(e) Documents - these provide general information and background on identification of NPS pollution and on potential control measures.

(c) EPA Water Planning Division - This set of documents is presently being issued. Separate manuals for each NPS category address the Best Management Practices (BMP) which have been identified as pertinent to that category. They are designed to assist the planner interface effectively with technical specialists in identifying and assessing the significance of NPS problems from various categories. BMP documents will cover agriculture, silviculture, construction, hydrologic modifications, mining and residuals management.

These sources of information, along with numerous other reported studies, yield a valuable data base for continuing analysis and implementation of control programs. The discussion provided in the balance of this chapter, together with both the cited references and the secondary references which can be developed from their review, can provide the planner with a starting point and the framework for a planning effort appropriate to his study area, for addressing NPS pollutants that are significant in his area.

4.6.1 Agriculture (Excluding Irrigated Agriculture)

Nonpoint source pollutant problems resulting from agricultural activities are difficult to reduce to a simple set of specific sources, loads, controls, and implementation. Problems arise because of the pervasiveness of activities within watersheds; the almost infinite array of activities/practices possible; the changes in practices which can usually occur annually; and the diversity of chemicals, application rates, and methods available to individual producers. The conjunctive use of agricultural lands for crop production and disposal (or utilization) of animal wastes is yet another spectrum of activities having potential for loadings which require a specific set of controls. These factors exist, unfortunately, in addition to the normal variations associated with the hydrologic system described in Section 4.2.2

4.6.1.1 Activities and Practices

The control of nonpoint source pollutant loadings is different from control of point sources in one key way - control is obtained only through source management and cannot be achieved by only knowledge of effluents (runoff). This fact requires the analyst to become familiar with each land use activity before any realistic problem assessment or subsequent control program can be developed. Comprehensive analysis requires a definition of activities more detailed than those in Table 4-3. No complete description of each activity for each crop and for every part of the country exists. Several reports are available, however, that describe cultural systems for specific crops (36-39). These references, in addition to local information available from state universities, provide excellent overviews of the mechanics for specific agricultural crop production. For example, references on wheat production describe the nature and timing of field operations, fertilizer and pesticide application recommendations, compatible rotations, etc., in use where wheat is grown.

4.6.1.2 Pollutants

The knowledge of the use and scheduling of these activities permits an evaluation of pollutant-generating practices, the delineation of pollutants, and most importantly, an insight into feasible management practices for control. The advantages of having a general knowledge of agricultural production are considerable when implementation of controls is desired.

Certain activities are common to all crops and can be considered collectively. Most notable among these (related to nonpoint source pollutants) is the application of fertilizers and pesticides. Several references are available that give detailed descriptions of pesticide properties, intended use, toxicity data, persistence, and relative mobility in soils (40).

Similarly, fertilizer technology and environmental behavior has been reviewed in recent publications (41, 42). Some of these references are production-oriented, but the basic data give useful insights to potential problems and their control.

Data for the distribution of various crops throughout the country and the associated planting and harvesting dates have been compiled and reported in a USDA Handbook (43). Listings by crop and geographical areas are included. The resulting time "windows" for planting and harvesting also suggest times when chemical applications are made and pollutant-loading analyses, similar to that illustrated by Figure 4-14, can be completed. More comprehensive analyses (e.g., via ARM, ACTMO) also require information of this type.

In addition to crop production management, agricultural waste management is an activity which is requiring more attention as semi-confined and concentrated livestock and poultry feeding increases. In some situations these waste sources are technically (and legally) considered to be point sources of pollution and, therefore, subject to the appropriate point source discharge permit regulations. Point source controls notwithstanding agricultural lands remain the ultimate recipient of solid and liquid wastes and nonpoint source load potentials must be evaluated. Two key EPA reports, now in preparation and soon to be published, describe livestock operations, wastes generated, and available controls (44, 45).

4.6.1.5 Control Practices

Chapter 4 has thus far been devoted to a discussion of NPS loading assessment. However, the specification of needed controls is the ultimate objective of a loading assessment. One of the most complete and useful source of information currently available for the selection of agricultural pollution controls is the two-volume report jointly prepared by the USDA and EPA referred to several times previously (2, 4). This manual points out controls available for erosion, runoff, nutrients, and pesticides. A methodology for selection of control practices, complete with flow charts and examples, is given in Volume I. A detailed interpretive review of existing literature is given in Volume II. These volumes are complete, have been designed specifically for use in development of nonpoint source control plans, and represent the state-of-the-art for agricultural sources. They are recommended for use in the development of water quality management planning. Similarly, the manuals for agricultural waste management, which are being prepared (44, 45) have been specifically designed to facilitate their use in environmental planning and decision-making.

Additional references (11, 13, 14, 15, 16, 20, 27, 32, 35) potentially useful in problem assessment, selection of controls, and implementation of plans have been previously discussed and will not be addressed here.

4.6.2 Silviculture

The major differences between agricultural and silvicultural activities are their frequency and areal extent within a given watershed. An agricultural rotation can extend from one to five years, while silviculture cycles are keyed to tree growth and extend from 20 to 80 years. Land use activities impacting nonpoint source loading, therefore, occur over relatively short time periods followed by a much longer recovery period. For example, clear-cutting to remove vegetation is a drastic change in the watershed, but recovery (if proper management steps are taken) is relatively rapid.

4.6.2.1 Activities and Practices

The broad categories suggested in Section 4.2.1.2 apply to silvicultural systems nation-wide. The U.S. Forest Service has further defined these activities in a joint Forest Service-EPA report (46). The major activities are categorized and defined as follows:

1. Vegetative manipulation by mechanical means: Any activity (excluding timber harvest and road construction) that uses mechanized equipment to alter or remove vegetation is included in this category. Mechanical site preparation for reforestation after timber harvest or for species type conversion is the most significant operation. Because such practices are somewhat limited by ground slopes, the most widespread use of these techniques is in the lower elevations common to the southern and southeastern United States. Dissmeyer (47) has described several treatments including chopping; chopping and burning; chopping, burning, and bedding; KG-blading; windrowing and burning; KG-blading, windrowing, burning, and bedding; and bulldozing, windrowing and burning. The area subjected to these treatments varies widely and depends on the size of cut or extent of type conversion desired.
2. Road and trail construction and maintenance: Access systems are a necessary part of any timber harvest system and include a variety of permanent roads, spur roads, skid trails, and landings. Some are continually maintained, while others are returned to natural vegetation

after harvest is complete. The pollutants most characteristic of silviculture activities are those associated with road construction and maintenance. The EPA-FS report cited previously (46) is an excellent overview.

3. Fire: Fire management systems include the use of fires for undergrowth control, slash disposal, and wildfire control. Wildfire itself can expose vast areas to erosive and leaching processes.

4. Grazing: Although not a silvicultural activity, grazing may constitute a major land use within timber areas. The pollutants are similar to those in agricultural activities.

5. Timber harvest: Only those activities directly associated with cutting and removal of trees are considered here. Access roads and reforestation, integral parts of harvesting operations, have been discussed separately. Various harvesting systems, extent of areal disturbance, and pollutants have been described (48, 49).

6. Recreation: Multiple use of forest lands is a common practice on public lands. Camping, recreational travel, fishing, and hunting can result in problems ranging from waste disposal to site maintenance.

7. Chemical use: Intensive timber management often includes applications of fertilizers and pesticides. Forest fertilization of established tree stands is a growing practice in northwest and southwest. Although less is known about pesticide usage, both insecticides and herbicides are used. A recent review of silviculture chemicals usage in the northwest is available (50).

4.6.2.2 Pollutants

The major impact exerted on the forested watershed results from the exposure of soil surface to erosive and leaching processes. The major pollutant (by volume) is sediment. Some operations, particularly timber harvest, increase water yield, accelerate oxidation of organic matter, and result in increased levels of plant nutrient discharge. The most comprehensive review of these problems and a description of the available data for each is included in the EPA-FS report (46).

4.6.2.3 Control Practices

Control of pollutants generated by silviculture is achieved through source management. A comprehensive selection methodology for controls is being developed. Several reports (46, 48, 51) describe control measures and further elaborate on specific activities listed above.

4.6.3 Construction

Construction activity is estimated to influence about 1 million acres (somewhat less than 0.2% of the total land area of the U.S.) at any one time. This includes construction for housing, highways, dams, and the like. The major pollutant resulting from construction is sediment. Although gross yields are relatively small compared with other NPS categories because of the smaller area affected, site-specific loads can be high and localized adverse impacts often result.

Several elements [illegible] control or reduction of pollutants from construction activity more practical than from other NPS activities. This results from (a) the relatively localized nature of the activity, (b) the on-site concentration of men, facilities and equipment during the construction process and (c) the ability to plan or modify specific activities in order to minimize pollution potential.

Because the occurrence of runoff is a function of the local climatic events which can be highly variable, pollutants from construction sites can change drastically and unpredictably. Also, the nature and quantity of pollutants depend upon the project phase, soil characteristics, local topography, and geologic conditions, the magnitude of people and equipment involved, extent of protective vegetative covering on the site, and other factors.

Control measures for this category will be directed at (a) minimizing the generation of pollutants, and (b) minimizing the runoff of those which are generated.

4.6.3.1 Activities and Practices

In analyzing the potential for the generation of pollutants from this NPS category, it is useful to make a distinction between construction activities, and construction practices. Activities are characterized in such a way that a distinction is made among (a) transportation and communication networks, (b) housing, (c) energy networks (power plants and transmission lines), (d) water resource development (dams, canals), and (e) recreational developments (parks, ski slopes). Generally, all will give rise to nonpoint pollution. However, basic differences in area affected, proximity to water sources, and predominant construction practices employed make it likely that specific problems and controls will be more or less consistent within an activity and different from other activities.

Construction practices may be defined as specific categories of job operations - for example, clearing and grubbing, grading, construction of facility, and site restoration. For any type of activity, each of the practices have a particular potential for the generation of pollutants. The potential for both the type of pollutant and the magnitude of the load differ with the particular practice, so that this characterization provides a useful frame of reference within which to assess pollutant loads and control measures.

Construction practices refer to the individual jobs performed in a construction project over a period of time. Each practice has a different potential to produce pollutants.

Clearing, grubbing, and pest control are construction practices typical in the first stage of a construction activity. During these operations unwanted vegetation including trees, bushes and sod is removed from the original site. In addition, herbicides may be applied to remove unwanted vegetation from the area.

Rough grading is the next step in most construction projects. During this phase the soil is moved from one place to another to obtain desired surface elevations. Grading may involve cutting and filling of slopes for highway projects, excavating or filling for buildings, or excavating for pipeline or canal installations. Heavy machinery used in this practice can be responsible for creating substantial amounts of petroleum waste products. In addition, the effects of moving and disturbing soils and subsoils can alter their physical characteristics to make them easily eroded when impacted by rainfall.

Rough grading is followed by final grading and facility construction. The constructed facility is different for transmission structures, highways, buildings and dams, but it is at this time that all construction sites encounter much physical activity. Equipment and machinery are in use, products and materials are on the site and workers are the most active. Pollutants generated during facility construction include chemicals, trash, sanitary wastes, cement and trace metals.

The final construction practice is that of site restoration. This includes cleanup of the site, final grading in some areas, tilling, establishment of permanent vegetation, removal of temporary structures and any other activities that restore the site to a balanced landscape. It is principally at this time that fertilizers are applied and nutrient runoff can be generated.

4.6.3.2 Pollutants

Sediment is the principal pollutant by weight that can result from construction. During a precipitation event, soil particles are eroded, transported, and deposited at other locations. Sediment may be deposited on land at the bottom of steep slopes or transported to a water body. Once in the water body, the soil particles may be further transported to areas of deposition where the stream velocity is less than that required to keep the sediment particles in suspension.

Pesticides are another type of nonpoint source pollutant. They include insecticides, herbicides, and rodenticides. These chemical compounds may adhere to the soil particles or dissolve in the runoff water and be transported off the construction site during runoff events.

Other nonpoint pollutants include petroleum products such as gasoline, diesel fuel, oil, grease and solvents. Some oils are used for dust control which requires that they be applied directly to the soil. These products become pollutants through their general use and misuse on the construction site.

Other chemicals may be used on the construction project for site preparation, facility construction, or for site restoration. Chemicals used to develop desirable soil properties are lime, fly ash, asphalt, phosphoric acid, salt and calcium chloride. Additional chemicals used during construction include pastes, oils, paints, solvents, dying compounds, cleaning compounds, and concrete curing compounds.
In addition, the construction site usually contains an excess of damaged building products, packaging and other miscellaneous garbage. Garbage can take the form of food containers, cans, coffee containers, empty cigarette packs, and general refuse. If they are not collected, they may eventually be transported to the nearest stream or water body.

Sanitary wastes are generated on construction sites by the work force. This type of pollution is generally controlled by using portable facilities. However, sanitary wastes may still reach the water bodies and be a source of pathogenic organisms.

Metals are used extensively for most types of construction projects. When pipes, beams, wire mesh etc., are left exposed to weather conditions, they eventually oxidize. During precipitation events, surface runoff may transport these oxides off the construction site to the stream.

Cement can become another source of water pollution if loose materials are not stored in a dry location out of the weather. The most common source of pollution from cement results from the washing of cement transporting vehicles or batching facilities. This washing is generally done in a batching plant area or where cement is to be placed often without regard for closeness to a stream.

Nitrogen and phosphorus compounds are used at construction sites for fertilizers. Some of these compounds may adhere to soils and can be washed to adjacent streams during runoff events. In addition, nutrients can dissolve in water and pollute both surface waters and groundwater.

4.6.3.3 Control Practices

Best Management Practices on a construction site are measures to control erosion, sediment and stormwater runoff. Each method is designed to minimize the pollutants being transported off the site as a result of a runoff event.

Erosion control measures prevent the transport of soil particles. These practices reduce both energy and velocity of the runoff thereby reducing its erosive powers. Erosion controls minimize soil exposure, control runoff, shield the soil and bind the soil.

A method to reduce erosion is surface roughing of slopes. Roughing includes tracking and scarification of slopes to slow the movement of runoff. Diversion structures such as soil or stone dikes, ditches, terraces and benches may also be used to control runoff by diverting runoff from sensitive areas. When diversion structures are used they may be used in conjunction with disposal structures which transport the diverted runoff without causing further pollution. Disposal structures include flexible downdrains, sectional downdrains, flumes, and level spreaders.

Vegetation can also be used to reduce erosion by protecting the ground surface from rainfall impact, binding the soil particles in place, and filtering out sediment which may be transported. Temporary stabilization is attained by planting fast growing annual and perennial plants, and provides short-term protection during construction delays or until permanent vegetation has become established. Permanent stabilization involves the planting of permanent vegetative materials such as grasses, legumes, vines, shrubs, native herbaceous plants, and trees.

Soil stabilization on a temporary and/or permanent basis can also be attained through the use of nonvegetative controls. Nonvegetative temporary stabilization practices include the use of mulches, nettings and chemical binders which hold the soil in place or protect it from rainfall energy. More permanent controls include gravel slopes, retaining structures, bank protection, and instream grade stabilization structures.

Control of pollution from construction sites also involves sediment control. Sediment controls prevent sediment transport off the constuction site. These controls include both filtering and ponding of runoff.

Filtering of surface runoff can be effected by vegetation. Common vegetative filters include natural buffer strips, installed buffer strips, center strips, and soil inlet filters. These filters remove sediment and debris from the runoff. The filters also slow the runoff thereby reducing its erosive capability.

Structural devices often are used in sediment control to intercept and detain runoff allowing the sediment to settle out, and to remove large debris. Structural devices are designed for the lifetime of the construction project or may be permanent and continue to operate after construction is complete. These devices include gravel inlet filters, sediment traps, and wet and dry sedimentation basins.

Although sediment is the major pollutant by weight generated as a result of construction activity, the other pollutants discussed earlier in the section must also be controlled. Partial control would be accomplished through the use of sediment control practices identified in this section. However, total removal of all other pollutants could be attained only by appropriate wastewater treatment, and would be expensive. The best methods to control these other pollutants are good housekeeping practices. These practices are not expensive to implement, however, they do require care and awareness by the workers, supervisors, engineers and planners. These practices are discussed in detail in the literature (16).

Good housekeeping practices involve the proper application of materials such as nutrients and pesticides when necessary. They also include proper disposal of solid and sanitary wastes. Finally, the construction activity should use the most effective type and amount of materials and properly dispose of the unused materials along with the other solid wastes.

Although the need for controlling runoff from a construction site has gained a degree of recognition, that of controlling excess runoff after development has not been fully recognized. Replacing natural open spaces by paved areas and buildings lowers the overall water infiltration capacity of a site which, in turn, leads to increased stormwater runoff.

When stormwater enters directly into a stream, the increased velocity may cause accelerated erosion of the stream channel. Where this runoff enters existing sewer systems, the system capacity may not be adequate to treat the increased flow and this could result in the discharge of poorly treated or untreated wastewater to the stream.

Stormwater management methods provide means to controlling runoff, reducing stream channel erosion and sediment discharge, and the release of pollutants contained in the stormwater runoff. Among those methods is the temporary storage and regulated release of runoff from small storms.

The following is a list of typical stormwater management practices which have been used in urban areas or on construction sites in non-urban areas:

1. Roof Top Ponding
2. Parking Lot Ponding
3. Diversion Structures
4. Ponds
5. Retention Basins
6. Porous Pavement
7. Holding Tanks
8. Infiltration Systems
9. Stream Channel Storage and control
10. In-Line Sewer Storage

The best water pollution abatement plan is one which minimizes or prevents erosion, sediment and runoff damages. No one single management practice can fulfill this task. An adequate water pollution abatement plan will contain many of the control practices discussed in this section. In addition, the best plans are based on a site inspection of the area and a data evaluation. If evaluated early enough, a construction activity or project may be adjusted or relocated depending on the sensitivity of the area. Any plan evolved should include feedback to allow for adjustments depending on the field activities.

4.6.3.4 Annotated Bibliography

1. "Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Source Pollution," Environmental Protection Agency Publication 430/9-73-014 (October 1973)(52).

This report includes a discussion of construction activities as one of the major nonpoint sources of pollution significantly influenced by the commercial activities of man.

Estimates are presented of the land area influenced and erosion rates for construction relative to agriculture, silviculture and mining. Significant pollutants likely to be contributed by each source are discussed.

Approximately 30 pages, devoted to the discussion of construction as a source of nonpoint pollution, provide a concise summary of types of activities and types of practices which can influence the potential for generating NPS loads, the type of pollutants and methods of pollutant transport. The report distinguishes between construction activity and construction practice. It characterizes five general classes of activity, each of which could be expected to influence NPS load generation in a different manner and possibly dictate different broad approaches to problems. For any of the types of activity (e.g. housing, dams and canals, etc.), a series of construction practices are identified and their relation to NPS load generation are discussed. Potential pollutants which could be generated from construction activities are identified and their source and potential significance are discussed.

The section of this report dealing with construction can provide the 208 planner with a good overview and perspective on the potential for pollution from construction activities.

2. "Processes, Procedures, and Methods to Control Pollution Resulting From All Construction Activity," Environmental Protection Agency Publication 430/9-73-007 (October 1973) (53).

This report presents information on processes, procedures and methods for controlling sediment, stormwater, and pollutants other than sediment which result from construction activities. The processes examined include site planning, preliminary site evaluation and design, use of planning tools, and structural and vegetative design considerations. The procedures examined include relative processes at Federal, State and local levels necessary to control land disturbing activities. Methods discussed include on-site erosion sediment and stormwater management control structures, as well as soil stabilization practices.

This report emphasizes planning as an essential element in the control of nonpoint pollution originating from construction sites. A pollution control plan should be an integral part of the project and should start as early as the site selection. In addition, control of pollution as well as the other engineering factors should control the timing of certain construction activities. The project design should also include plans to protect the environment, such as the installation of temporary stream crossing structures prior to construction, proper disposal of petroleum wastes, etc.

The major section of the text discusses the on-site methods which are available for the control of erosion, sediment, and stormwater. Structural, nonstructural and vegetative control techniques are addressed. Sketches and photographs of a variety of pollution control devices are provided although detailed design considerations are not covered. It provides a useful introduction to the devices which are available and discusses how these devices are useful in the control of nonpoint pollution.

For the planner, this report will be useful for obtaining background information on the processes and methods available to control nonpoint pollution originating from construction activities. For an engineer, it emphasizes the importance of the total site evaluation and planning ideology, and can be used as a source of references to the more technical manuals which are available.

3. EPA, Nonpoint Source Pollution Control Guidance Construction Activity, (In Progress) (54).

The objectives of this report, presently in draft form, are to identify management practices which will reduce or control generation of pollutants from construction activities, and to provide guidance to 208 planner in evaluation or selecting measures which may be appropriate in this area.

The document contains four chapters. Chapter 1 discusses approaches to identifying and assessing the existence of problems. The discussion is general in nature and describes possible approaches. The approaches discussed include:

(a) making a general survey of existing and recently completed construction projects to determine the extent of pollution.

(b) examining water quality data (coincident with the construction activity) to determine if the activity was harmful to the waterbody.

This chapter also discusses the various physical observations which should be made to help indicate whether significant erosion has taken place. In addition, methods for making gross estimates of the quantity of eroded soils are presented in this chapter.

Chapter 2 discusses the procedures which may be helpful to make an analysis of the construction activity and its effect on the surrounding water bodies. The section is brief and very general and primarily identifies types of data which may be useful in the evaluation of nonpoint runoff and control and the sources from which it may be procured. Discussion of control approaches provides a broad overview, and essentially identifies the principles to be considered.

Chapter 3 discusses several of the techniques aveilable for the control of erosion, sediment and stormwater. Erosion control practices include both vegetative and structural devices. Vegetative control practices are described in general terms while the engineering details are contained in cited literature. As a guide for the design of erosion, sediment, and stormwater control structures, some preliminary information and sketches are given. In addition, the references necessary for a more detailed examination and design of the control devices are presented in the text. Using the Universal Soil Loss equation to estimate sediment runoff, the final section in this chapter estimates the amount of sediment generated on a construction site after control devices have been added. Also, estimates of the changes in the input parameters of the soil loss equation with changes in control devices are made.

The thrust of Chapter 4 is a presentation of a methodology for the assessment of potential pollution problems and their magnitude. Sediment is the major pollutant addressed. Using the Universal Soil Loss Equation, sediment losses from areas without control devices are estimated. Charts and tables are presented to enable the users to calculate the USLE input parameters. Finally, references are given throughout the chapter directing the reader to more detailed information on the methodology.

This manual will assist both a nontechnical planner and an engineer in assessing and evaluating pollutants which result from construction activities. However, for a complete design or evaluation, it may be necessary to augment this information with data that is presented in the cited references.

4. "Comparative Costs for Erosion and Sediment Control, Construction Activities," Environmental Protection Agency Report 430/9-73-016 (July 1973) (55).

This report presents installation costs for certain erosion and sediment control devices which may be used to minimize nonpoint runoff from construction activities. This information is documented for more than 25 pollution control practices in current use in both the eastern and western United States. Most of the data presented were obtained from the Walnut Creek Watershed in central California and the Occoquan Watershed in Virginia.

The report describes erosion and sediment control structures. It includes photographs and sketches of the control structure being discussed. Detailed installation cost data is provided for the particular control devices.

Cost data is provided for the removal of sediment which originates at construction sites and which has been translocated to a deposition point by rainfall runoff. Removal methods examined include excavation and dredging. Limited data are presented for the cost of removing sediment from runoff by water treatment.

The text also discusses the USLE as a method of estimating sediment loss. All graphs and charts that are necessary to make quantitive estimates of soil losses using the USLE are presented. The USLE is also used to analyze the effectiveness of erosion and sediment structural and nonstructural control measures.

The text includes a cost evaluation example problem which developed from information presented in previous sections. The example problem gives additional insight to the chapter since it shows the reader exactly what input data is needed, how it is handled and processed and how the data can be used to make performance and cost effectiveness estimetes.

The material presented in this report aids either an engineer or a planner who knows what the NPS problem is and which control solutions are available. This report will then help the engineer calculate the cost and effectiveness of the given control structures or techniques. An actual cost figure would require an adjustment of the estimate through one of the acceptable indices.

5. "Standards and Specifications for Soil Erosion and Sediment Control in Developing Areas," U.S. Dept. of Agriculture, Soil Conservation Service (56).

The report presents specifications for the design of erosion and sediment control structures. The standards and specifications were prepared by the Soil Conservation Service while providing technical assistance through the Soil Conservation Districts in Maryland. A general background to erosion phenomena and sediment control is presented in the report. However, this presentation is short and should not replace the background information on erosion, sediment and the respective control techniques and procedures which are presented in other references discussed earlier.

The first section of the report is concerned with temporary structural practices. The text defines the structural practices, gives the purpose, describes the condition where the practice applies, and lists the design criteria and construction specifications. In addition, each structure is illustrated with a standard engineering drawing which includes a copy of the construction specifications. The drawing with the specifications is useful in that it contains all the information necessary for a field engineer or supervisor. The text also gives any of the mathematical equations which are necessary for the structural design. If graphs or nomographs are needed to solve the design equations, then they are also presented.

The report then describes the standards and specifications for permanent structural practices. Because these are permanent structures, their design and their specifications receive more attention than did the temporary structures. For most of the structures detailed hydraulic considerations are included in the design. However, all equations, nomographs and illustrations are included.

Vegetative control practices are discussed next and on the same level of detail as both temporary and permanent structures. When applicable, vegetative seeding procedures and the installation dates for certain vegetative covers are given, as well as fertilizer application dates and application rates.

Finally, standards and specifications for other nonstructural practices as discussed. These activities include bank stabilization, topsoiling, tree protection and other miscellaneous topics not covered in the earlier sections.

It should be recognized that this is a highly technical manual, and is less useful than some of the others cited in the planning stages of a water pollution control project. In these early stages, the other more general background literature, cost literature and effectiveness of control literature should be consulted. The information in this manual will be most useful when the proper control structure has been selected and it is time to design the site specific structures and implement their construction.

4.6.4 Hydrologic Modification

Hydrologic modifications result from activities that alter the natural flow patterns of surface and groundwater. Water quality impacts may be realized from hydrologic modifications both during facility construction and after the project is operational. The pollutant problems resulting from the construction phase of the project are discussed in the section on construction activities, Section 4.6.3, while the problems resulting from the completed hydrologic modification are discussed below.

The various types of hydrologic moficiations which may already exist, or may be proposed for a 208 planning area are identified and discussed in this section. The different types of pollutants which may affect the study area are presented, and various control strategies are analyzed. An annotated bibliography is also provided to indicate more detailed sources of information for the assessment of hydrologic modifications.

4.6.4.1 Activities and Practices

Hydrologic modifications can be grouped into channel modifications, impoundments and reservoirs, dredging and other resource recovery operations and water use systems. Channel modifications are generally for flood control or for improved drainage, and they provide an increased channel capacity. This allows for the passage of a greater volume of flow. Flood control modifications include channel clearing and snagging, channel excavations and channel realignment. Other modifications are sometimes made to tributaries of the main channel for flood and stormwater control. These include the construction of retarding basins and debris basins. Modifications of the drainage pattern may be accomplished with drainage ditches and surface or groundwater pumping.

A general result of channel modifications is an increase in stream velocity. The velocity increase is caused by a decrease in the stream roughness or by the straightening of the channel. However, the increased velocity may sometimes exceed the channel stability velocity and will cause bottom scour and bank erosion. In addition, when work is performed in the stream channel, the stream shoreline is usually disturbed by the movement of equipment. During these construction activities, shoreline vegetation may be removed or killed. The destruction of vegetation can result in an increase in the incident solar radiation. This, in turn, can result in an increase in stream temperature.

Hydrologic modifications which result in the depletion or lowering of groundwaters can impair quality in both surface and subsurface waters. Fish and wildlife habitats may be reduced from the increased infiltration of stream waters, seasonal water temperature patterns may be modified, and seawater intrusion may occur in coastal areas.

Impoundments are constructed for power generation, flood control and water supply. Those impoundments used only for power generation are known as run-of-the-river impoundments. Run-of-the-river impoundments have a time of flow passage of approximately a few days or less and, therefore, do not confine a large volume of water. Another type of impoundment is a reservoir storage impoundment which can have a time of flow passage of many months. These are the large reservoirs which are used for water supply and flood control. These storage reservoirs often result in significant water quality problems.

The depth of the large reservoirs combined with the incident solar radiation usually creates thermal stratification of the water impounded on the upstream side of the dam. The more common pollutional problems downstream of the dam are caused by the release of water which is warmer or colder than the downstream water temperature and the release of water which is low in dissolved oxygen and supersaturated with nitrogen.

Instream resource recovery operations such as dredging are another type of channel modification. These operations can cause nonpoint source pollution when the extraction of the materials from the streambed is taking place. If the benthos contains settled sewage or other waste products, these pollutants may become resuspended during the dredging operations. Additional problems can occur from the changes in bottom substrates and biological habitats and alterations in water velocity and current patterns.

4.6.4.2 Pollutants

Sediment is normally generated during the construction of hydrologic modifications. After the completion of the channel modifications it is possible that an increased stream sediment content will also persist because of the higher stream velocities that are present in the stream. Sediment deposition may also be a problem at the upstream end of impoundments: as the water flows into the impounded area, stream velocities decrease and the suspended sediment may settle to the stream bed.

Instream water temperatures are affected by incident solar radiation which reaches the stream if channel modifications remove or reduce the natural vegetative covers. In addition, thermally stratified water layers are created in reservoirs because of the incident solar radiation and the depth of the water. Depending on the outlet point of the reservoir, the thermal increases or decreases can occur in the downstream water temperatures.

Other pollutants such as nutrients, herbicides, insecticides, trace metals, other chemicals and soluble organic compounds, may exist in the benthic muds. When the muds are disturbed, such as in dredging or other channel alterations, these pollutants can be resuspended. In the case of impoundments, the natural leaching processes can transport these pollutants from the benthos to the water column.

4.6.4.3 Control Practices

Control practices to be followed during the construction phase of hydrologic modifications are the same as those discussed in Section 4.6.3.3 for general construction activity. Best management practices for channel modifications attempt to reduce the erosive force of the stream flow. Site preparation and reduction of thermal stratification are practices which reduce the nonpoint source pollution for impoundments.

Best management practices for control of nonpoint source pollution originating from channel modifications reduce the stream velocity and, therefore, reduce its erosive forces. The velocity reduction may be obtained by increasing the channel roughness or decreasing the channel slope. Rocks and stones (of local origin whenever possible) can be used to increase channel roughness and/or stabilize banks. Riffle and pool areas can also be built into the channel modifications to dissipate energy and, additionally provide areas of stream reaeration. If the channel cross-sectional area is increased for flood control, a low-flow channel should be provided within the new channel. This low-flow channel can be constructed with the same physical characteristics as the original channel. When major channel modifications are performed, the bends in the river should be designed to prevent erosion of the banks. The usual method for this is to have steep outside banks and shallow inside banks. In addition, stones can be used on the outside banks to protect them from erosion.

Temperature increases can be controlled by the proper planning of vegetative cover. Whenever possible, natural vegetation should be left undisturbed during construction. In addition, permanent vegetation should be planted upon project completion to provide soil stabilization and shade cover conditions similar to those which existed before construction.

Control of spoils removed from the channel is an additional measure necessary to control nonpoint source pollution. These spoils are usually placed along the side of the stream. They should be prevented from returning to the river through erosion and runoff. This can be accomplished through proper sloping and immediate revegetation. In addition, spoils should be placed so they do not harm the natural vegetation.

Best management practices for control of nonpoint source pollution originating from impoundments include proper site preparation, control of release waters, minimization of stratification, and temporary algal and weed controls. Soil areas within the impoundment should be prepared for flooding. Timber, stumps, and man-made debris should be removed from the impoundment area. Grass, shrubs, organic mulches, and rich topsoils should also be removed. Finally, the bed should be covered by two inches or more of sand to prevent the leaching of materials out of the soil.

Outlets located at several levels can be used selectively to release waters in which the temperature and dissolved oxygen are consistent with downstream water quality. Conversely, thermal stratification in deep reservoirs could be avoided by mixing the impounded water via diffusers or other mechnaical means. Also, release waters could be reaerated mechanically or by outfall design in order to prevent the discharge of water having a dissolved oxygen deficiency.

In large impoundments, eutrophication may be a problem. The only control practice which provides long-term results for eutrophication control is to limit the nutrients entering the reservoir. Proper site preparation will aid in nutrient reduction. However, the amount of nutrients reaching the stream from upstream point and nonpoint sources can provide enough nutrients to eutrophy an impounded area. These sources should be controlled by point source nutrient removal processes and nonpoint source nutrient control practices.

Temporary solutions to eutrophication problems are often used when long-term solutions are not possible. Temporary solutions include harvesting of algae, cutting and removal of aquatic weeds, drowning of aquatic weeds and the use of herbicides.

4.6.4.4 Annotated Bibliography

1. "The Control of Pollution from Hydrographic Modifications," Environmental Protection Agency Publication -- EPA 430/9-73-017 (57).

This report presents a broad, general description of the environmental effects of hydrographic modifications. (Note that the term "hydrographic modification" is used instead of "hydrologic modification", although their meanings are the same.) The preparation of the report was mandated by Section 304(e) (1) and (2) part (F) of the Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500. Qualitative guidance is provided for identifying and evaluating pollution problems and possible control measures. Although quantitative, predictive methods are referenced, none are described in the report. In this respect, "The Control of

Pollution From Hydrographic Modifications" is well suited for an introductory overview of the wide range of possible problems and solutions.

The report discusses four general types of hydrographic modifications. These include:

1. Channel modification projects.
2. Impoundments and reservoirs.
3. Effects of urbanization.
4. Dredging operations.

For each type of project the current level of government involvement is discussed, including the activities of Federal, State and local agencies. Current practices are identified, as are the sources and types of pollutants which may affect the modified waterway. Methods of pollutant transport in stream channels and impoundments are examined, and water quality modeling and data collection are briefly described. The mechanics of groundwater pollution, such as that which occurs from seawater intrusion, is also discussed.

Methods, processes and procedures to control the pollution impact of projects are presented. Examples of these include design modifications to minimize adverse channelization impacts, structural and nonstructural alternatives to channelization, aeration and destratification of reservoirs, land use control, and productive uses of dredge spoil.

2. "Impact of Hydrologic Modifications on Water Quality," Environmental Protection Agency Publication -- EPA 600/2-75-007(1975) (58).

This report describes the scope and magnitude of water pollution problems caused by hydrologic modification activities that disturb natural flow patterns of surface water and groundwater. Although no new field measurements were made, a large body of available data is analyzed and presented.

The study has two principal purposes. The first is a description of the magnitude of water quality problems caused by the following hydrologic modifications:

1. Construction
2. Dams and impoundments
3. Channelization
4. Dredging
5. Land reclamation activities.

Quantitative estimates are made of the amount of sediment that enters the Nation's surface waters as a result of highway and urban construction. This section has the format of a nationwide assessment, and is primarily intended for use in EPA's program planning process. This analysis is supplemented by an Appendix with numerous case studies from each of the five categories of hydrologic modifications from around the United States. These summaries constitute a useful and concise compilation of extensive information and data.

The second purpose of the report is to develop "source loading functions" for predicting the quantities of water pollutants released by out-of-stream construction activities. These loading functions can be used by technical investigators to estimate the amount of sediment entering a watercourse from construction sites of known size and locations. The loading functions, which are adaptations of the USLE, are based on measurements of sediment yields and other parameters at ten construction sites. The accuracy and limitations of the functions are analyzed.

The report also includes a brief discussion of methods for controlling pollution from hydrologic modifications, including out-of-stream and instream approaches.

3. "EPA Nonpoint Pollution Control Guidance, Hydrologic Modifications," (in progress), Environmental Protection Agency, Water Planning Division (59).

This document presents the information needed by a water quality management or planning group in developing the management practices to minimize water pollution due to hydrologic modifications. The report is directed towards activities which modify the hydrology of an area, such as channelization, dams, dredging, and instream construction; as well as activities which unintentionally impact hydrologic characteristics, such as the land development which accompanies rapid urbanization. The information is qualitative, and specifications for technical design are not included.

The report describes approaches for assessing water quality problems from existing hydrologic modifications. The different types of modifications and the various pollutants which may effect them are discussed. These pollutants include:

1. Sediment
2. Nutrients
3. Thermal effects
4. Pesticides and other chemicals.
5. Biological microorganisms.

Possible sources for available information are identified and survey techniques for expanding the information are discussed.

Methods for the analysis and selection of control alternatives are also presented. Data needs are described, including climatic, geologic and topographic information. Selected practices for the control of water quality problems associated with hydrologic modifications are discussed in more detail.

The report includes a section on identifying potential problems from proposed projects. Analyses were made of primary problems such as flooding and landslides which could result from poor planning and design and secondary problems such as sediment control during construction.

The Appendix of the report presents some of the pertinent rules and regulations of the United States Army Corps of Engineers and the Environmental Protection Agency related to hydrologic modifications. They are reproduced from the Federal Register and include:

1. U.S. Army Corps of Engineers, "Permits for Activities in Navigable Waters or Ocean Waters"
2. Environmental Protection Agency, "Navigable Water, Discharge of Dredged or Fill Material"

The Appendix is useful for determining the legal considerations that may be involved in planning decisions.

4. "Report on Channel Modifications - The President's Council on Environmental Quality, United States Government Printing Office," (March, 1972) (60).

This report, prepared for the Council on Environmental Quality discusses forty-two selected channelization projects performed by the United States Army Corps of Engineers, Soil Conservation Service, Tennessee Valley Authority, and the Bureau of Reclamation. An assessment is made of the environmental, economic, and engineering aspects of the channel modifications. The methodology used in preparing this report is a good guide for those evaluating additional projects.

The projects chosen for discussion represent a variety of climatic and topographical conditions, soil type, Aquatic and habitat systems, rural and urban locale, and a range of project purposes and sizes. Each site evaluation conducted by the study group consisted of a general project briefing session, a field survey of the area, and a concluding session with public participation.

Professional observations serve as a basis for evaluating the physical effects of wetland drainage and land use changes, cutoff of oxbows and meanders, watertable changes and stream recharge, erosion, sedimentation, and channel maintenance. The results of extensive biological investigations conducted by the Philadelphia Academy of Natural Sciences are presented. These are integrated into a useful format for evaluating the effects of channel modifications on fish and wildlife resources, habitat, species diversity, and productivity. Although there is little quantitative information presented based upon measurements of water quality or hydraulic parameters, the assessment procedures derived from professional observation and biological studies may be useful to the planner of additional projects

5. "Planning and Design of Open Channels," United States Department of Agriculture, Soil Conservation Service, Technical Release No. 25, December, 1964, Revised March, 1973(61).

This technical release is presented as a guide for use by field personnel in the evaluation, planning, and design of open channels. The material is directed toward the more complex type of channel work done by the Soil Conservation Service. This includes floodways and drainage-type channels in which channel degradation and bank erosion are of primary concern.

The report discusses general planning considerations such as the adequacy of outlets, legal requirements, and the rights-of-way. Guidance is provided for the preliminary survey, drawings, strip maps, and profiles. Examples of drawings are included.

Site investigations are described to evaluate the resistance of the soils in the bed and banks of the channel to erosion forces, to evaluate the sediment transport relationships, to determine slope stability against sloughing and sliding, to estimate earth loads that may act on structural members, and to determine the rate of water movement through the soils. Information for identifying and analyzing stratigraphic units (layers of soil) is presented, and procedures for sampling and testing the channel bed and slope are suggested.

The report presents a methodology for determining channel capacity and relating this to design discharges. Designs for special transition structures in waterways are examined. Criteria for slope stability are analyzed, and methods for improving channel slope stability are suggested.

The revised version of the report includes a section on environmental considerations in channel design, installation, and maintenance. Although no definitive criteria or standards are established for SCS projects, useful guidance is provided for the planner. Issues of aesthetic quality, fish, and recreation resources are addressed. Methods are presented for protecting these beneficial uses through design and during construction. The section on environmental considerations includes appendices with approaches and charts for rating the recreational and environmental quality of a project. The report provides useful technical information for the actual design and implementation of channelization projects.

6. "Water Quality Management Planning Methodology for Hydrographic Modification Activities," Texas Water Quality Board, (December, 1976)(62).

This report, prepared for the Texas Water Quality Board, develops a methodology for the evaluation of hydrographic modifications, the pollutant loads generated by associated activities, impacts on receiving water bodies, and pertinent control strategies. Although portions of the report pertain specifically to conditions in Texas, the approach and techniques presented are useful to planners seeking a straightforward analysis framework for evaluating hydrographic modifications.

The effects of hydrographic modifications are outlined by examining typical contaminants and relating them to instream impacts. These impacts include:

1. Aesthetic value
2. Dissolved oxygen depletion
3. Sediments and deposits
4. Excessive aquatic growth
5. Public health threats
6. Improved recreation value
7. Ecological damage
8. Reduced commercial value.

Water quality problems common in impoundments and reservoirs are identified and quantitative estimating techniques are presented. Issues of temperature, density, stratification, evaporation, and eutrophication are addressed. Solutions are given for pollutant concentrations in run-of-the-river impoundments, large vertically mixed and vertically stratified reservoirs, and two dimensional near-field effects. Simple, empirical methods for relating the eutrophic status of a lake to the nutrient loads are discussed. Example problems are included to demonstrate the techniques.

The pollution impact of channel modifications and dredging operations are also presented. Some of the issues addressed are the relationship between bank vegetation and water temperature, the effect on reactions, reaeration and the assimilative capacity of the stream, and the physical, chemical, and biological characteristics of dredged material. Relevant data needs and sources of information are discussed.

The report includes an analysis of pollution control methods for each type of hydrographic modification activity. Examples of those presented are site preparation, control of loads, selected withdrawals from reservoirs, aeration and destratification, control of nuisance organisms, reclamation of disturbed areas, and disposal site controls.

7. Reports from the United States Army Corps of Engineers.

A number of studies related to hydrologic modifications have been conducted by the U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi. A few of the available reports are summarized below.

a. "Mathematical Simulation of the Turbidity Structure Within an Impoundment," Research Report H-73-2 (63).

In this report, the thermal and turbidity structures of an impoundment are simulated with a mathematical model. The model was verified with observed data from the Hills Creek Reservoir in Oregon and used to predict the turbidity structure of a proposed impoundment. The effectiveness of selective withdrawal, in particular, a low-level outlet for controlling turbidity is examined. Examples of input and output from the computer program used for the analysis are presented.

b. "Selective Withdrawal from Man-Made Lakes," Technical Report H-73-4 (64).

This report presents the results of laboratory investigations to determine the withdrawal-zone characteristics created in a density-stratified impoundment by releasing flow through a submerged orifice, over a free and submerged weir, or through a combination of the above. Density stratification from differentials in both temperature and salinity are examined. Generalized relationships for describing the vertical limits of the withdrawal zone and the vertical velocity distribution within the zone are developed. This flow rate distribution can then be applied as a weighting function to the reservoir profile of water quality parameters to determine their concentrations in the reservoir release.

c. "Ecological Evaluation of Proposed Discharge of Dredged or Fill Material into Navigable Waters," Miscellaneous Paper D-76-17 (65).

This document is intended to provide interim guidance for the evaluation of discharges of dredged material as mandated in Section 404(b) of Public Law 92-500. The selection and interpretation of appropriate tests for dredging sites and dredged material are discussed. General approaches for technical evaluation are partitioned into physical effects, chemical-biological interactive effects, and procedures for site comparison. The report presents detailed stepwise procedures for conducting an elutriation test (to simulate the release of dissolved solids from dredged material), estimating a mixing zone, performing bioassays, conducting total sediment analyses, and evaluating biological community structure.

d. "Techniques for Reducing Turbidity Associated with Present Dredging Procedures and Operations," Contract Report D-76-4(66).

The reduction of turbidity from present dredging procedures is examined by analyzing the following operations: cutter performance, ladder, suction, hull, pipeline, connections, barges, tenders, personnel, inspection, contracts, plans, and specifications. The suggested techniques consist principally of good dredging procedures already known, but not always followed by dredging contractors and their personnel.

e. "B. Everett Jordan Lake Water Quality Study," Technical Report H-76-3(67).

This report is an example of a study on a large impoundment. Physical and mathematical models are used to investigate the hydrodynamics of stratified flow within the lake, to predict the temperature and dissolved oxygen regimes of the lake immediately upstream of the dam, and to estimate the temperatures and dissolved oxygen content of the release. The report provides an interesting example of applications of different modeling techniques used by the Army Corps of Engineers.

4.6.5 Mining

Mining refers to the extraction, transport, processing and storage of minerals and disposal of mineral wastes. Mining activities impact more than ten million acres of land in the United States. The types and quantities of pollutants generated from these mining operations are dependent on the substance being mined, rock type, climate, topography, geologic structure, method of mining, and hydrologic characteristics of the site. The detrimental effects of mining activities can be prevented, reduced, or eliminated by preventing the formation of pollutants at the mine site, containing the pollutants within the mining area once they are generated, and controlling pollutant contributions emanating from mining operation areas.

4.6.5.1 Activities and Practices

The extraction of mineral deposits from the earth is accomplished by surface mining, underground mining, well extraction, and a number of lesser methods including in-situ leaching.

Surface mining takes several forms such as strip, open pit, dredging, and hydraulic mining. Strip mining involves the removal of overburden to expose an underlying deposit for extraction. Open pit mining is a similar procedure for areas with little overburden. Open pit mines contribute minimal spoil, but result in deep open holes. Dredging is underwater mineral recovery. The material may be removed from artificial impoundments or natural bodies of water. Hydraulic mining incorporates the use of a high velocity water jet directed at unconsolidated deposits. Underground mining is directed at the extraction of minerals deep in the earth. Shafts are sunk to gain access to the deposit. Surface mining generally creates a more visible defacement and disturbance of the earth's surface than does underground mining. The placement and distribution of the mineral deposit determines the size, depth and method of the mining operation.

A mining operation progresses along a number stages of development including exploration; access and support facility construction; mineral extraction and processing; mine closure; mineral storage; and waste disposal.

4.6.5.2 Pollutants

Both surface and groundwaters can be adversely affected by active and inactive or abandoned mining operations. Pollution arises because hydrologic characteristics of surface or subsurface runoff may be altered when the earth is disturbed to gain access to mineral deposits. The degree of alteration and pollution generated depends upon the size, depth, and method of the disturbance and also on the chemical and physical properties of the disturbed material.

The major forms of water pollution resulting from mining operations include physical, chemical, and hydrologic changes. Most chemical pollution results from the oxidation of sulfide minerals. In the presence of water and an increased amount of oxygen due to exposure, accelerated oxidation of the ore may produce acid and salts, particularly iron salts and sulfuric acid. When these solutions contact mineral and soil formations, the acid may in turn selectively extract heavy metals.

Refuse waste materials that result from mining activities can be significant sources of pollution when surface or groundwater percolation is intercepted and produces a contaminated leachate. In addition, mineral wastes which contain pyrite will oxidize and form soluble iron salts and sulfuric acid. These may be flushed into nearby surface waters or percolate into groundwaters during a precipitation event.

Radioactivity arising from mining activities is primarily a concern in the western United States with regard to seepage of uranium and radium at sites where uranium ores are mined and processed. The effects of very long term exposure to low levels of radioactivity are of concern and are being studied.

The most common form of physical pollution is sediment. Surface mining creates large areas of disturbed land which are often highly erodible. The processing of raw minerals to concentrate ore creates vast piles of fine grained waste materials which are a potential source of sediment pollution. During contour strip mining operations, the practice of placing overburden on the downslope side of the outcrop can result in excessive siltation in water courses.

In summary, the most serious pollutants associated with mining and mineral operations are mine drainage contaminants and sediment. Mine drainage contaminants may include such constituents as acids, alkalis, iron, aluminum, manganese, zinc, cobalt, lead, mercury, cyanide, fluoride, copper, arsenic, cadmium, nickel, phosphate, sulfate, chloride, and radioactive mineral contaminants.

4.6.5.3 Control Practices

Mine water pollution control is generally achieved by preventing pollution production or containing pollutants on the mine site and controlling pollutant delivery to the receiving water. For both surface and underground mining, effective pollution control pre-planning can prevent, reduce or eliminate pollution from active mining areas and pollution that may occur after completion of mining. Such site characteristics as geology and ground water patterns, climate, soil and slope stability, chemical/physical nature of the overburden, past mining history and characteristics of receiving waters should thoroughly be investigated to determine the proper choice of mining methods and pollution control techniques.

4.6.5.3.1 Surface Mining - On-site Abatement

a. Controlled Mining Procedures: Certain mining procedures provide better control of water pollution than other techniques. The adaptation of one or more of the techniques is governed by the specific type of mining operation. Some of the controlled mining procedures are discussed below.

Overburden can be separated by type. Some overburden materials are conducive to plant life, while others are sterile or have the potential for polluting. The purpose of overburden segregation is to keep these classes of material separated during mining so they can be effectively utilized during later regrading.

Longwall strip mining is being researched as an alternative to conventional strip mining as a procedure which may reduce the pollution potential of the mining operations. A vertical trench is cut into a hill perpendicular to the mineral outcrop and the deposit is extracted with automatic mining equipment. There is little surface disturbance required when using this technique and most of the sediment related problems of strip mining are eliminated.

Other mining techniques in use are modified block cut, head-of-hollow fill, box-cut mining, area mining, auger mining, and selective mineral extraction. Any of these mining operations may result in more or less nonpoint pollution, depending on the characteristics of the particular site.

b. Water Infiltration Control: Infiltration results from subsurface water movements, or downward percolation of surface waters from rainfall. Pollution from water infiltration can be avoided by decreasing surface permeability, using impermeable barriers between the water source and the pollution forming material, diversion of water around the mine site, and underdrain utilization.

c. Handling Pollution-Forming Materials: Pollution-forming mining wastes discarded on the land surface may be exposed to oxidation, weathering, erosion and leaching. Mine backfilling and sealing, relocation of wastes to a more suitable hydrologic location, and flooding of underground mines to eliminate oxidation are several methods of controlling pollution from these materials.

Another technique is the utilization of mine wastes as saleable products. Reprocessing mine wastes for secondary extraction can eliminate or reduce waste piles.

d. Regrading: Regrading is the mass movement of earth to achieve a more desirable topography. The main purpose of regrading is to provide a suitable base for revegetation, burial of wastes, and reduction of erosion. The techniques will vary according to the topography of the final land surface.

e. Erosion Control: Erosion control is accomplished by several basic methods. One of these is the protection of erodible surfaces from movement by water. This is accomplished by water diversion and by covering procedures. Chemical stabilization, revegetation, mulching, slope control, and concentrated flow handling are methods of decreasing erosion potential at mine sites. Revegetation, specifically, is one of the most effective erosion control techniques. A dense ground cover stabilizes the surface with its root system, shields the surface from rainfall, and reduces velocity of surface runoff.

4.6.5.3.2 Underground Mining - On-site Abatement

a. Controlled Mining Procedures: For underground mining, water pollutants are generated after mining is completed by oxidation of the mined materials. Air circulating through an abandoned mine can therefore continue to oxidize susceptible materials. Flooding of a mine to exclude air is the only practical method of eliminating this source of oxygen under present technology. However, if a mine is flooded, the flooded water must be contained within the mine or it can itself become a source of pollution.

Most of the water entering underground mines passes vertically through the mine roof from overlying strata. Collapse of a mine roof is sometimes responsible for increased vertical flow. The chance of the collapse of overlying strata can be reduced by employing one or a combination of the following: pillars, roof support, limiting the width of openings, and by backfilling the voids.

b. Water Infiltration Control: These techniques are designed to reduce the amount of water entering underground mines, and subsequently to reduce the amount of drainage leaving the mine. Choice of techniques and extent of their use will depend on hydrologic conditions in the area and cost effectiveness of each technique. Infiltration generally occurs as a result of rainfall recharge to the ground water reservoir. Rock fracture zones and faults have strong influence on ground water flow patterns. Infiltration can usually be reduced by avoiding these zones during mining. Boreholes and other fractures can be sealed up to reduce the movement of water.

filling surface depressions, smoothing overlying areas, or other surface regrading techniques can be used to decrease water infiltration.

c. Mine Sealing: This practice is usually employed to promote inundation of underground mine workings in order to reduce oxidation of pyritic materials. Mine sealing involves construction of a physical barrier in a mine opening to prevent passage of air and water. A mine seal can be constructed in many ways, using many different types of material. A mine seal must have internal strength capable of withstanding water pressure, and it must be tied into the floor, roof, and sides of a mine opening. Some seal types and methods which have been successfully demonstrated include double bulkheads, gunite, grout curtains, clay and air seals.

4.6.5.4 Annotated Bibliography (Mining Activity)

1. U.S. Environmental Protection Agency, "Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Sources of Pollutants," EPA 430/9-73-014 Washington, D.C., (October 1973) (68).

This report provides documentation of presently available knowledge in four areas of nonpoint sources of discharge, namely, agriculture, silviculture, mining and construction. In the seventy-page chapter on mining, the nature and extent of pollution from mining activities is discussed, data interpretation aids are given and prediction methods pertaining to pollution sources from mining are presented.

The report discusses the nature of the sources, the type and relative importance of pollutants from each source, and the pollution loads related to natural and operational factors. General discussions on acid mine drainage, sediment, leachate, and radioactivity are included. Discussions are given on groundwater pollution and subsidence from abandoned underground mines. Details of some coal mine drainage pollution problems are presented. Pollution sources from other mining activities discussed in less detail include the mining of hard rock minerals; stone, sand and gravel; nonfuel sedimentary materials; and oil and gas.

Statistical information on inactive and abandoned mines, and sources of current statistics on active mining operations are also provided.

The empirical aids for mine drainage data interpretation that are presented in the report consist of nomographs which permit a check of the anion-cation balance of a sample. The use of the nomographs and interpretation of the results obtained from them are discussed, as is the conversion of raw water quality data into useful form. Trends (correlations) that were observed for stream quality data in mine drainage areas are also presented. A discussion of sampling techniques and procedures, and analytical methods that are usually performed for mining-related wastewater, is presented. Brief descriptions of models that have been developed for predicting pollution quantities are also presented together with indications of their applicability and success. These include models to determine flow and chemical characteristics of mine drainage, limestone requirements for pyritic spoils and overburden, infiltration of water into spoil banks, leachate quantities from spoil banks, pollution potential from spent oil shale, mine drainage volumes in localized areas, and sediment loadings.

This report presents a general overview of information to identify and evaluate the extent of nonpoint sources of pollutants stemming from mining activities. The reader may use this information as a guide to more elaborate and comprehensive discussions of the previously mentioned topics relating to mining activities. A list of seventy references are presented at the end of the mining section of this report and are footnoted in appropriate sections of the text.

2. U.S. Environmental Protection Agency, "Processes, Procedures and Methods to Control Pollution from Mining Activities," EPA-430/9-73-011, Washington, D.C., (October 1973) (69).

This report provides information that identifies and evaluates available technology for control of water pollution from mining activities. Information is presented on techniques of at-source water pollution control applicable to the mining industry, whose practicability and feasibility have been demonstrated, or strongly indicated by the results of research. The control methods included in this manual are identified and described by way of brief text, generalized illustrations, and unit cost indications where possible.

The manual is divided into three major components, namely, surface mining, underground mining, and treatment of mine drainage. Discussions of various controlled mining procedures, methods to control water infilitration, and techniques used to handle polluted mine waters are presented for surface mining and underground mining operations. The section on surface mining also contains methods of handling pollution forming materials, discussions of various types of regrading, erosion control procedures, and revegetation techniques. Numerous methods of mine sealing underground mines are also presented. The treatment section of the report discusses neutralization of mine drainage utilizing various limestone and lime processes. Subsections under treatment of mine drainage include discussions on sludge disposal, evaporation processes, reverse osmosis, electrodialysis, ion exchange processes, freezing (crystallization), and iron oxidation.

The manual serves to acquaint the reader with the many available techniques to control pollution from mining activities. It does not provide the degree of detail that would be needed for it to be used alone as a pollution control reference. However, the manual may be used to guide the reader to the appropriate reference or references for specific, detailed, comprehensive information on how to apply a particular technique.

3. EPA Technology Transfer Seminar Publication, "Erosion and Sediment Control, Surface Mining in the Eastern U.S.," Volume I: Planning, Volume II: Design, EPA-625/3-76-006, (October 1976) (70).

This manual consists of two volumes. Volume I covers the basic concepts of erosion and sediment control and implementation of the control plan. Volume II discusses design and construction considerations, erosion control materials, and provides a sample of an erosion and sediment control plan.

The mechanics of soil erosion and sedimentation and the physical factors which determine the nature and extent of these processes are discussed in Volume I. Included are presentations of the methods of erosion and sediment control and maintenance of control practices. The various aspects of an erosion and sediment control plan and implementation of this plan are also discussed.

Volume II of this manual discusses the design procedures and construction specifications for selected control structures. Included are diversion structures, sediment traps, downdrain structures, level spreaders, grassed waterways, ripraps, check dams and sediment basins. Erosion control products and materials, such as chemical binders, mulches, and other stabilization materials are also discussed. A sample of an erosion and sediment control plan, selected state mining laws, and reclamation information are also presented.

This manual contains comprehensive discussions of various aspects of erosion and sediment control. Volume I provides numerous figures and photographs which aid the reader in obtaining a thorough explanation of the need for control, basic control principles, available technology for erosion and sediment control, and procedures for preparing and implementing a control plan. Similarly, Volume II is a detailed design manual, containing numerous tables and figures of design parameters and construction specifications for various control structures. Example problems and a sediment basin design example are also included. The manual provides lists of references after various sections, as well as a glossary. It should be noted that the control information presented is directed primarily toward preventing excessive soil loss and resulting damage associated with coal surface mining operations in the eastern portion of the United States, specifically the Appalachian, eastern interior, and western interior coal regions. However, much of the material and certainly all of the basic erosion and sediment control philosophy are applicable to all categories of surface mining in all regions of the country.

4. "EPA Guidance for Identification and Assessment of Mining Nonpoint Pollution Problems" (in Progress)(71).

The problem assessment procedures that are presented in this document are intended to help state and areawide 208 agencies to better understand and carry out their planning responsibilities specifically related to mining nonpoint sources under Public Law 92-500. This guidance presents a simplified approach for planners to use in making an initial identification of mining nonpoint source problems and suggests alternative judgements and decision points that are involved in the definition of mining planning requirements. The document suggests a task outline for identification and assessment of mining nonpoint sources and provides procedures for chosing the location and description of mining pollution, interpretation of water quality data, existing pollution load description, quantitative load characterization, and mining pollution load analysis.

B. Bituminous Coal Research, Inc., Mine Drainage Abstracts (73).

These abstracts are an important information source regarding what has been published in the area of mine drainage research and in treatment and control technology. Annual supplements published each year contain information received that year pertaining to all aspects of mine drainage. The bibliography and supplements are available at a nominal cost from the Library, Bituminous Coal Research, Inc., 350 Hochberg Road, Monroeville, Pennsylvania 15146.

4.6.6 Residuals Management Practices

Residuals management practices deal with the disposal of residual waste materials. Residual waste materials are generally considered to be but are not limited to wastewater treatment plant sludges, septage effluent and pumpage, water treatment sludges, municipal refuse, combustion and air pollution control residuals, industrial waste sludges, feedlot manure, mining wastes, and dredge spoils. The residuals management practices vary widely depending on the residuals and the land area.

4.6.6.1 Activities and Practices

Residual management can be separated into utilization practices and disposal practices. The utilization practices are designed to reduce the amount of residual by conversion to a resource. Disposal practices are strictly designed to dispose of the residual waste products.

Residual utilizations differ for each of the types of residuals. Wastewater and water treatment plant sludges can be used for fertilizers and soil conditioners after they are stabilized and dewatered. In addition, the lime and alum can be removed from these sludges and reused. Municipal refuse may be either recycled, or incinerated for use as an energy source. A common use of combustion and air pollution control residuals is for coarse aggregate material used in roadbed construction. There are numerous recovery methods and uses for industrial waste sludges. Each reuse depends directly on the characteristics of the sludge and therefore on the industrial product. Finally, mining wastes can be used for road construction materials or for incinerator combustion materials.

Disposal practices for residual wastes are diverse and in some cases, complex. Each practice generally includes the operations of site selection, evaluation, disposal, control and monitoring. The disposal operations are categorized as land reclamation, land spreading, sanitary landfills, ocean disposal, and trench disposal. Any single disposal method can not normally be used for all of the previously cited residuals.

Land reclamation includes the reuse of strip mines and marginal lands, and the creation of wildlife habitats. In each of these practices, residuals are deposited on land through spray irrigation, pipeline slurries, and hopper scows. These practices are generally used for the residuals listed below.

1. Wastewater sludge
2. Septage
3. Water treatment sludge
4. Feedlot wastes
5. Dredge spoils

A second residual disposal practice is land spreading. Land spreading is normally accomplished by spray irrigation, ridge and furrow application, plow-furrow-cover application, plow-injection application, subsoil injection, truck application and manure spreading. These operations are used for the liquid slurry residuals listed below.

1. Wastewater sludge
2. Septage
3. Feedlot wastes
4. Dredge spoils

Another residual disposal practice is sanitary landfilling. In sanitary landfill operations, residuals are applied to the land, compacted, covered with soil and compacted again. This process is repeated until the landfill is completed. The landfill is closely monitored to insure that both the groundwater and surface water are not contaminated by leachate. Generally, municipal refuse comprises the largest fraction of residual in a sanitary landfill. A landfill can accept sewage, septage and water treatment sludges if proper pretreatment and dewatering is practiced. Sanitary landfills are often used for disposal of combustion air pollution control residuals and incineration residuals. Industrial wastes and sludges are usually deposited in separate areas of the sanitary landfill, while mixing, feedlot and dredging residuals are not normally disposed of in sanitary landfills.

Ocean disposal is another residual management practice although operations of this type are being significantly restricted. This practice has been utilized extensively in the past for disposal of all types of residuals. However, recent legeslation limits the mixed concentration of the residual and water to 0.01 of the concentration which is detrimental to the appropriate sensitive marine organisms. This will tend to eliminate ocean disposal of all residuals except dredge spoils.

Trench disposal is another land application method. Residual wastes are placed in trenches approximately two feet deep. The trench is then immediately covered with soil to prevent odor escape and surface water contamination. The only residuals which have normally been disposed of in this manner are digested and raw dewatered sludges. Trench disposal is not a commonly used method, since the period required for stabilization may be as long as five years.

4.6.6.2 Pollutants

Pollutants generated from residual management practices vary according to the practice employed and the residual itself. The pollutants have been listed in Table 4-5 according to the residual waste product.

Nitrogen and phosphorus are potential pollutants which originate in wastewater sludge, septage, and feedlot manure. Organic materials are generally derived from septage, water treatment, municipal refuse, feedlot and dredge spoil residuals. Potential sources of heavy metals are wastewater sludge, septage, water treatment sludge and municipal refuse. Micro-organisms originate from all biological residuals.

To assess the pollutants from these residual management practices, the planner must examine the residual. Next, he must examine the method of disposal. Finally, he must examine the control practices used in the site to monitor the possible pollution of surface and groundwater. It is not likely that the quality or the quantity of the pollutants can be assessed without site specific water quality data. However, these data normally exist for some of the residuals management practices in the planning area.

4.6.6.3 Control Practices

Residuals managment is practiced to dispose of residual waste materials while at the same time eliminating and minimizing one of the nonpoint sources of pollution.

The first step in a management plan is to minimize the volume of waste material for disposal. A second requirement is the treatment of the residual to the state-of-the-art treatment level available. Such treatment methods include stabilization, dewatering, neutralizing, etc.

Examination of the disposal site is required. The site should be chosen so that the residual waste does not become a source of pollution upon disposal. For example, an industrial sludge containing heavy metals should not be used to fertilize a corn field. Likewise, salt water dredge spoils should not be applied to land as fertilizers due to their high salt content.

It is during the site planning that the meteorologic, geologic, and hydrologic characteristics of the disposal site should be examined. In developing a disposal plan, disposal site conditions should be compatible with the properties of the residual in order to give maximum protection to both the ground water and surface water.

For a sanitary landfill, pollution control practices should include the installation of proper drainage systems to divert surface water away from the fill area. An impermeable liner can also be installed to protect the groundwater. Additional control measures depend largely upon the specific waste under consideration.

Other general management practices for pollution control of residuals will depend on the residual and the conditions of the disposal site. These methodologies are not described here. However, the many pollution controls options for the residual management practices are available in the literature.

4.6.6.4 Annotated Bibliography

1. "Effects of Land Disposal of Solid Wastes on Water Quality," Department of Health, Education, and Welfare, SW-5, Bureau of Solid Waste Management, Cincinnati,(1968) (73).

This pamphlet is an informative review of current literature which describes the influence of solid waste disposal practices on water quality. Definitions, site descriptions, water quality criteria, potential hazards, case histories, recommendations, and tentative guides are included. The information is designed to give some insight into the problems that may occur and the methods for solving them.

A section describing open dumping and sanitary landfill as major land disposal methods is presented. Included are discussions of infiltration and percolation, solid wastes decomposition processes, gas production and movement, leaching, groundwater travel and direct runoff, and the role each plays in contributing to surface and groundwater pollution due to land disposal.

Evidence that physical characteristics, biological quality, and chemical composition of surrounding waters are affected by quality and quantity of solid waste conditions is well known. The physical characteristics of major concern are turbidity, odor, taste, and color. Biological water quality refers to bacteria present in the water, usually by leaching. Chemical composition is concerned with mineral and organic substances present in solid wastes which are capable of causing gross pollution of underground water supplies. Of major concern are chlorides, organic matter, hydrogen sulfide, carbon dioxide, methane, ammonia, and nitrates.

Case studies of water quality investigations related to solid waste disposal operations are presented. These case histories are samples of past investigations and some present research efforts presented to clarify the potential pollution problem associated with refuse disposal sites.

Requirements for proper land disposal are presented. Recommended land disposal methods for surface water wet areas such as swamps and marshes, tidal areas, ponds, quarries, and similar depression type areas are discussed. Actual requirements enforced in several municipalities are outlined.

In addition to requirements, suggested guides to enable management to judge the acceptability of a waste disposal site are listed. These include the areas of study required prior to design and construction of sanitary landfills. Also included is a listing of guides to good practices which is essentially a list of "DO's" and "DON'T's" with regard to land disposal practices.

2. "Residual Management by Land Disposal," Proceedings of the Hazardous Waste Research Symposium, EPA Report No. 600/9-76-015, Cincinnati, (July 1976) (73).

The report contains information on extramural research projects funded by the Solid and Hazardous Waste Research Division of the U.S. Environmental

Protection Agency, Municipal Research Laboratory in Cincinnati, Ohio. The papers presented in the proceedings are separated into five sections, as they were categorized in the symposium.

The first section, "Introduction and Orientation" presents an overview of Federal research and legislative development programs for hazardous waste disposal.

The second section, "Identification of Pollution Potential" deals with techniques for gathering and interpreting information about problems with disposal of hazardous wastes. The authors indicate that there is a need for a program of disposal research. They also describe some of the methods used to observe the effects of land disposal of hazardous wastes on environmental quality.

Available techniques for dealing with potential disposal problems are presented in the third section, entitled "Modification of Disposal Sites and Waste Streams." Chemical stabilization of the waste or soil and/or use of impermeable liners in order to prevent groundwater contamination are discussed.

The fourth section, "Special Disposal Problems," is a discussion of problems encountered in disposal of specific types of wastes. The wastes are highly concentrated and/or highly toxic substances such as hexachlorobenzene, vinyl chloride, and pesticides.

Movement of contaminants in soil is discussed in the fifth section, "Predicting Trace Element Migration." The section includes discussions of predictive and modeling procedures, techniques and problems of detecting contaminant movement, and determination of the soil properties and contaminant characteristics which control movement.

3. Solid Waste Management: D. Joseph Hagerty, Joseph L. Pavoni, John E. Heer, Jr.; Van Nostrand Reinhold Environmental Engineering Series, (1973) (75).

The book offers a look at the environmental problems and solutions associated with solid waste collection and disposal. Included are data which show how future systems for collection, disposal, and recovery will have to be designed and selected. In addition, discussions are included regarding the pros and cons of presently used systems, innovations in collection equipment, and specialized practices and facilities for transport and collection of solid waste.

Equipment is described which is capable of being modified to specific ways of handling almost any type of solid waste. The many types of compaction and size reduction equipment are discussed. Presentations of separation techniques and material and energy recovery systems are included. Ways and means to reduce the volume to be collected while recovering larger amounts of highly valuable materials are shown. Recovery of valuable materials is an incentive to the pursuit of environmental goals.

In its discussion of sanitary landfills, the book includes information on the design and planning stages, equipment requirments, site selection considerations, relative costs of landfilling, prevention of resulting pollutional problems, and use of the completed sanitary landfill.

A discussion of incineration is also included. The basic process principles are discussed, and information is given regarding the planning, design, construction, and operation of refuse incinerators and their accessory apparatus.

The authors outline the economic advantages, environmental aspects, and other factors involved with the new developments and equipment in the field of solid waste management. Discussions of high-temperature incineration, power generation through incineration, pyrolysis of wastes, new landfill stabilization techniques, and landfill disposal of hazardous wastes are included. Finally, the text outlines the legal, environmental, and public relations aspects of solid wastes management.

4. "Management of Hazardous and Toxic Wastes," Paul N. Cheremisinoff, William F. Holcomb, Pollution Engineering, Vol. 8 No. 4, April 1976, pp. 24-32 (76).

Hazardous wastes continue to be a significant problem, even as air and water pollution control and solid waste disposal methods progress. The authors point out that the generation rate of non-radioactive hazardous wastes is estimated in excess of 10 million tons annually and increasing, or about 10 percent of all waste material generated by industry.

Included are several definitions of "hazardous wastes" as given by the Hazardous Materials Transportation Act of 1974, Federal Water Pollution Control Act Amendments of 1972, and the National Solid Wastes Management Association. The authors also indicate that disposal of wastes on land is essentially unregulated except in the case of radioactive wastes. The EPA is in favor of a program which would establish a nationwide Federal and State regulatory program.

An extensive discussion of present disposal practices is included. In making use of existing technology, hazardous wastes can be generally dealt with by reduction in quantity generated by process modification or raw materials changes; by concentration of wastes at the source by evaporation, precipitation, etc.; by stimulation of waste exchange -- recovered acid, caustic, or solvent wastes may be sold or recycled; by recovery and recycle of metals, energy content and other useful resources contained in the wastes; by destruction of some hazardous wastes by special incineration methods; by detoxification and neutralization for land disposal; and by construction of specially designed landfills, insulated from groundwater, and properly monitored and secured.

Finally, a section on "International Disposal Techniques for Other-than-high-level Solid Radioactive Wastes" is presented. In the section, disposal methods such as shallow land burial, disposal into mines and deep geological formations, deep sea disposal, deep well disposal, and packaging are discussed.

5. "Stop Leachate Problems," Michael Bilal; John F. Lenard, Water and Wastes Engineering, Volume 12 No. 10, October 1975, pp 27-40(??).

Controlling leachates is one of the most important aspects of sanitary landfilling. The degradation of surface and groundwaters as a consequence of landfill operations remains a problem, especially in humid areas where precipitation is considerable.

The authors visualize leaching as a special case of extraction of substances adsorbed onto solid particles. The transfer of pollutants from the refuse to the groundwater is accomplished by vertically or horizontally moving water which directly passes through, and has intimate contact with the refuse.

Leaching takes place only if a section of the landfill is at saturation, or field capacity. Any additional moisture beyond field capacity generates leachate. Landfills containing large amounts of paper can retain significant quantities of water without any leachate formation.

The authors discuss the type of information required prior to design of the landfill. Subsurface characteristics of the site, including geologic and hydrologic patterns are required. Well studies, borings, and soil surveys provide the data for design. From the data, water table contour maps, cross-sections of the landfill site, groundwater flow patterns, soil transmissibility, groundwater velocities, and infiltration capabilities are determined.

Further discussion of each of the aforementioned developments is presented. Finally, a case history design of a sanitary landfill in Ledyard, Connecticut is discussed. The methods described in the article were used in the design.

6. The Report to Congress: Waste Disposal Practices and Their Effects on Groundwater, Executive Summary, U.S. Environmental Protection Agency, Office of Water Supply, Office of Solid Waste Management Programs, April 22, 1976 (78).

The report is a summary of an investigation into (a) disposal of waste (including residential waste) which may endanger underground water which supplies, or can reasonably be expected to supply, any public water systems, and (b) means of control of such waste disposal.

The study covers waste disposal activities which result in the actual collection and disposal of liquid, semi-solid, and solid wastes. In addition, resulting contaminants from the disposal practices are defined and their various routes to the groundwater system are outlined. Some of the wastes studied are industrial wastes contained in surface impoundments, municipal and industrial refuse and sludge, septic tank and cesspool wastes, municipal sewage, stormwater runoff, waste brine from petroleum industry, solid and liquid mining wastes, and animal feedlot wastes.

The report is divided into fifteen sections. The first three sections are concerned with the importance of groundwater as a resource, its nature and extent, and the ways in which it becomes contaminated. The following nine sections of the report are concerned with common waste disposal practices. The disposal practices are discussed in conjunction with the types of wastes discussed in the preceding paragraph. The next section discusses contamination of groundwater due to sources other than waste disposal practices. The final two sections of the report are concerned with existing federal legislation with regard to groundwater contamination and discussions of state and local alternatives for groundwater quality protection.

7,8. Solid Waste Disposal, Volume 1: Incineration and Landfill and Volume 2: Reuse/Recycle and Pyrolysis, Baum, B. and Parker, C., Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, Vol. 1 1973, Vol. 2 1974(79).

Volume 1 of this book provides valuable information through a detailed examination of two methods for the disposition and disposal of solid wastes. The practice of incineration is treated in terms of its history and its design criteria for both municipal and industrial wastes, capital and operations costs, instrumentation and control of air pollutants. Landfill practices and the design, construction, administration, and economics of sanitary landfill operation are discussed.

Volume 2 explores the vital aspects of reuse, recycling and reclamation of plastic and non-plastic solid waste, with particular emphasis on ways to preserve our natural resources, reduce pollution, conserve energy and reduce costs. Finally, the authors analyze government activity and legislation in this area and project into the future of solid waste management and utilization, including a discussion of the latest disposal methods.

Recovery of solid waste now represents less than 5% of total solids disposed of by homes, industry, commerce and government. The importance of this 2-volume study is that it not only surveys current problems and methods of solid waste disposal, but also presents solutions that can play a significant role in protecting and preserving our environment.

9. "Disposal of Sewage Sludge into a Sanitary Landfill," Report No. SW-71d, U.S. Environmental Protection Agency(1974) (80).

This report describes the results of a three-year investigation of the environmental and economic effects of disposing liquid sewage sludge and septic tank pumpings into a sanitary landfill. The objectives of the study were to determine: (1) the capacity of solid waste to assimilate the moisture in liquid sewage sludge and septic tank pumpings; (2) the significant parameters affecting that capacity; (3) the optimum means for nuisance-free admixture of liquid sludge with solid waste in a landfill; (4) the effects of combined liquid sludge-solid waste disposal on the environment, landfill equipment, operating efficiencies, and personnel performance; (5) the effects of liquid sludge on landfill compaction and solid waste decomposition; and (6) the most economically feasible methods for dewatering, transporting, and disposing liquid sludge.

The three-year study included laboratory evaluations of water absorption by solid waste, pilot-scale simulation of landfill conditions, full-scale field test cells for controlled landfill simulation, full-scale demonstration of liquid sewage sludge disposal into a sanitary landfill, and characterization of the sewage sludges and solid wastes generated by the City of Oceanside. A special nationwide survey of the disposal of sewage sludge and septic tank pumpings into sanitary landfills was made by contacting responsible State public health authorities and municipal landfill managers.

10. "Residual Waste Best Management Practices: A Water Planner's Guide to Land Disposal," Environmental Protection Agency Publication, EPA-440/9-76-022 (in progress)(81).

This handbook describes residual wastes from nine most frequently encountered sources and relates management of these wastes to exhaustive enumeration of Best Management Practices. The solid waste problem assessment procedures that are presented in this report will provide the potential users-planners, engineers, administrators, lawyers, elected officials, and others with a reference for carrying out their residual waste management responsibilities under areawide or state water quality management planning programs and other regional and local activities.

Suggestions are presented for the identification and assessment of residual wastes nonpoint sources and methods are given for the location and description of pollution associated with solid waste disposal. Also included are methods of interpretation of water quality data and description and characterization of loads associated with disposal of solid wastes.

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CHAPTER 5

ANALYSIS OF STREAM IMPACTS FOR URBAN AND NONURBAN SOURCES

5.1 Introduction

The preliminary assessment methodology presented in Chapter 2 provides analysis techniques which can be used to identify existing and potential water quality problem areas. The methods are set in a rather broad planning context which sacrifices details within the study area in favor of regional load assessment and problem area identification. In effect, Chapter 2 provides the 208 planner with planning tools which permit him to reduce the dimensionality of his problem, that is limit the number of river miles and water quality variables which should be subjected to more definitive analysis.

Chapter 5 presents methodologies for more detailed assessments of existing and potential problem areas identified in the preliminary problem assessment phase of the 208 program. In this regard, Chapter 5 includes another level of detail for assessing water quality in streams. Simplified modeling methods are described for determining receiving water quality responses to continuous and intermittent loads described in Chapters 3 and 4. The time and space scales of the modeling framework are reduced from those in Chapter 2. Spatial resolution in the analysis described in Chapter 5 ranges from local to sub-basin scale. The time scale permits an evaluation of water quality response characteristics over the course of a few weeks. This is in contrast to the steady state average annual water quality responses generated in Chapter 2. The principal water quality variables considered in these time and space scales are BOD, dissolved oxygen, suspended solids, total nutrients and coliform organisms. The principal emphasis in the chapter is on urban loads.

Special techniques are described for simplifying the structure of the water quality analysis in streams. These include guidelines for aggregating loads or for treating local distributed loads as point sources and simple methods for incorporating dispersion estimates into the stream analysis. Finally the chapter presents an example stream analysis which draws on load generation techniques and modeling methods presented in Chapters 2, 3 and 4. The example proceeds from the development of the variable loads through model application. Special sub-sections of the chapter cover model calibration and methods for developing time dependent results from steady state water quality models.

Lakes, estuaries and coastal areas are also considered in Chapter 5. The level of detail employed in these analyses is less sophisticated than that for streams, and is similar in scope to the preliminary assessment techniques employed in Chapter 2. The reason is that lakes, estuaries and coastal areas are characterized by complex transport mechanisms, the analysis of which is not easily structured in the simplified form which characterizes advective transport in streams. Furthermore, the nature of water quality problems in these systems frequently requires multi-dimensional analyses or solutions involving complex reactions and interactions between variables, and are beyond the scope of the present manual.

Chapter 5 does, however, present methods for identifying and analysing existing and potential water quality problem areas in complex water bodies. In certain cases, these methods will be satisfactory by themselves. In others, the analysis will point to problems which can only be satisfactorily resolved with numerical modeling techniques. Criteria for making these distinctions are presented in this chapter.

Finally, Chapter 5 presents guidelines for using numerical computer models to analyse specific problems which are not amenable to analysis techniques described in this manual.

Chapter 5 presents a simplified procedure for analysing a set of complex and very sophisticated water quality problems, those associated with stormwater. The analysis includes methodologies for assessing storm water impacts in streams which can be performed with an electronic calculator or with relatively simple computer programs which are readily available. The purpose of this analysis is to reduce the complexity of the water quality modeling effort to the point where reliable assessments of storm water impacts and their controls can be made with a minimum expenditure of resources.

The methods in this manual are not viewed as a replacement for more sophisticated storm water modeling frameworks. Instead, they are designed to be part of the 208 planner's library of analysis tools. Until this time, there has been no reliable storm water evaluation methodology which could be used to determine storm water control requirements in the time frame of a few weeks. Most storm water programs require at least that time to develop the data input for the model. The present method is designed to satisfy the need for a reliable yet inexpensive evaluation of storm related problems.

The method employs steady state water quality models of stream systems. In this regard, the fundamental tools are classical and familiar to most 208 planners. The method, however, yields results which contain a great deal of time variable information. Consider a stream which is subjected to pulse loadings from storm events. The water quality response can be viewed as a series of pulse storm water responses which spread as they move downstream. The steady state model must be interpreted in a very specialized way in this case. First, the response represents the worst water quality condition at each point downstream, as the pulse travels downstream. Secondly, the model results are attenuated in the downstream direction, reflecting the natural attenuation of the peak response due to longitudinal dispersion. Other refinements and modifications to the steady state model are also included in this chapter. Each of these are included to maximize the time variable information content developed from the model.

5.2 Stream Water Quality Analysis Methods (Non-Steady State)

Steady state stream analysis has been generally considered to be of limited usefulness in evaluating the water quality response due to non steady state loads. The problem centers on the inability of the steady state model to represent transient water quality responses due to short term load variations. However, because of the ease with which steady state water quality models can be developed and applied, they are frequently used to make estimates of extreme conditions which might result from a time variable load. For example, it is a common practice to use short term loading extremes to estimate extreme water quality occurrences. An analysis of this type is presented in Section 2.7.1.2 (pg. 2-101) where a steady state model is employed to evaluate dissolved oxygen response in the hypothetical South River under an extreme storm event (extreme high flow, extreme wet weather load). The analysis is reasonable, since the duration of the loading event is sufficiently long to approach steady state in the River.

Recent developments, however, have extended the capabilities of simplified analyses in assessing transient water quality responses. Analysis techniques presented in this chapter consider the time variable response to continuous and intermittent loads using modified steady state models. The methods are consistent with others in this manual in that the analysis techniques can be performed without the assistance of computerized numerical models. Before considering these methods, a brief discussion of model verification and calibration is presented at this point because it is clear that an adequate representation of water quality responses can be developed only if the adequacy of the model can be demonstrated by a comparison against field data. These models can be computerized numerical models or, as is used in this chapter, the equations in Table 2-17 (pg. 2-83).

5.2.1 Criteria for Model Verification

Water quality projections have an associated level of reliability which is related to the models ability to reproduce observed receiving water responses in the particular study area being considered. That is, if a model has been developed, its reliability in making forecasts is assessed by its ability to compute water quality similar to that measured in field data collection programs. The methods by which reliability is developed is called model verification analysis.

There are a number of levels of model verification which can be pursued ranging from gross comparisons of computed water quality with a single set of grab samples to a comprehensive verification, which utilizes data sets collected at many combinations of river flow, seasonal factors (temperature, rainfall, etc.) and loading.

The degree to which any model should be verified is normally decided on the basis of:

1. The degree of confidence which must be maintained in the model projections;
2. The potential range of costs which could result from management decisions that the model outputs will impact;
3. The range of flow, temperature, and loading conditions which the model will be used to evaluate;
4. Resources available for model development and testing.

Generally the last item, cost, is an overriding concern since model verification is costly and time consuming. As the model application proceeds in a continuing planning process, factors 1 through 3 may dictate additional model verification work to develop more detailed input to the planning process.

Calibration is a term applied to verification analyses which are limited. Normally full model verifications require model comparisons with three to four complete sets of observed data, while calibrations normally rely on a reduced data base with fewer, or less complete data sets.

Since stream models applying methods contained in this chapter are to be used in generating step 1 planning guidance, some model calibration is justified and encouraged. The level of verification required must be decided on a site specific basis using the four criteria cited above as guidelines. In most cases because of a lack of extensive historical data, model calibration against 1 or 2 sets of available data will be a practical upper limit.

5.2.1.1 Model Calibration Analysis

Model calibration consists of four tasks: Data preparation and analysis, preparation of model input, model application and comparison of model results with measured water quality data.

Chapter 2 describes possible sources of historic water quality data and presents some examples of data presentation methods which are appropriate in a model calibration exercise. For example see Figures 2-2 (pg. 2-12), 2-3 (pg. 2-13), and 2-13 (pg. 2-47). Normally, companion data are available to establish the appropriate river flows, Table 2-3(a) (pg. 2-23), and seasonal temperature, Figure 2-12(b) (pg. 2-35). Chapter 3 provides some guidance in the preparation of loading data. Efforts should be made wherever possible to gather loading data from measurements collected during the receiving water quality surveys. Where data collection is required to develop a data base for model verification, the Monitoring and Surveillance Appendix to this manual provides guidance in developing adequate programs.

The data is then assembled in a manner consistent with the input requirements to the model. Finally, the model results are compared to measured data and an evaluation is made as to whether the model adequately reproduces the observations. If not, the model input data (temperature, flow, load measurements, depths, etc.) should be refined or modifications made in the model coefficients.

When the calibration is judged to be acceptable, the following criteria should be satisfied:

1. Model loads and river flows should be those which were measured.
2. Model coefficients should be within acceptable limits described in Chapter 2.
3. Model coefficients should be internally consistent and should not vary indiscriminately from segment to segment.
4. The computed water quality should at least reproduce major trends in the observations. It is not necessary for the computed water quality profile to go through every data point.

An example of an acceptable calibration using the South River data is demonstrated in Figure 5-1. The calibration analysis indicates that the South River model is only in marginal agreement with the observed suspended solids concentrations. Additional effort should be directed toward refining the model loads which were poorly defined in the existing data base. Calibration of other water quality variables appears to be adequate. A second calibration analysis would enhance the reliability of the model considerably.

Section 5.2.1.1 has reviewed the basic elements of model calibration in general terms, allowing a certain amount of latitude because of the Phase I planning function of models developed in this chapter and the site specific nature of water quality problems and verification requirements. A more definitive description of model calibration and verification procedures can be found in references (1, 2) and in the model applicability Appendix.

5.2.2 Time Variable Load Characteristics

5.2.2.1 Continuous Loads

Time variable loads are broadly categorized as continuous and intermittent. Continuous loads are those which are always or nearly always discharging within the time scale of the analysis. The magnitude of the loading, however, can be variable in time. For most applications the non-steady state characteristics of continuous discharges can be ignored because the load variability is small relative to the mean loading, at least within the time scale of the problem. For example, most municipal and industrial discharges have relatively constant dry weather mass loads. This is shown schematically in Figure 5-2(a).

Other municipal loads may exhibit large load variations reflecting the inflow characteristics of combined sewer systems. In such cases, the load might be treated as constant only during dry weather periods, and the loading dynamics might have to be incorporated into the receiving water analysis during wet weather simulations. The degree to which this distinction has to be made is dependent upon the magnitude of the load

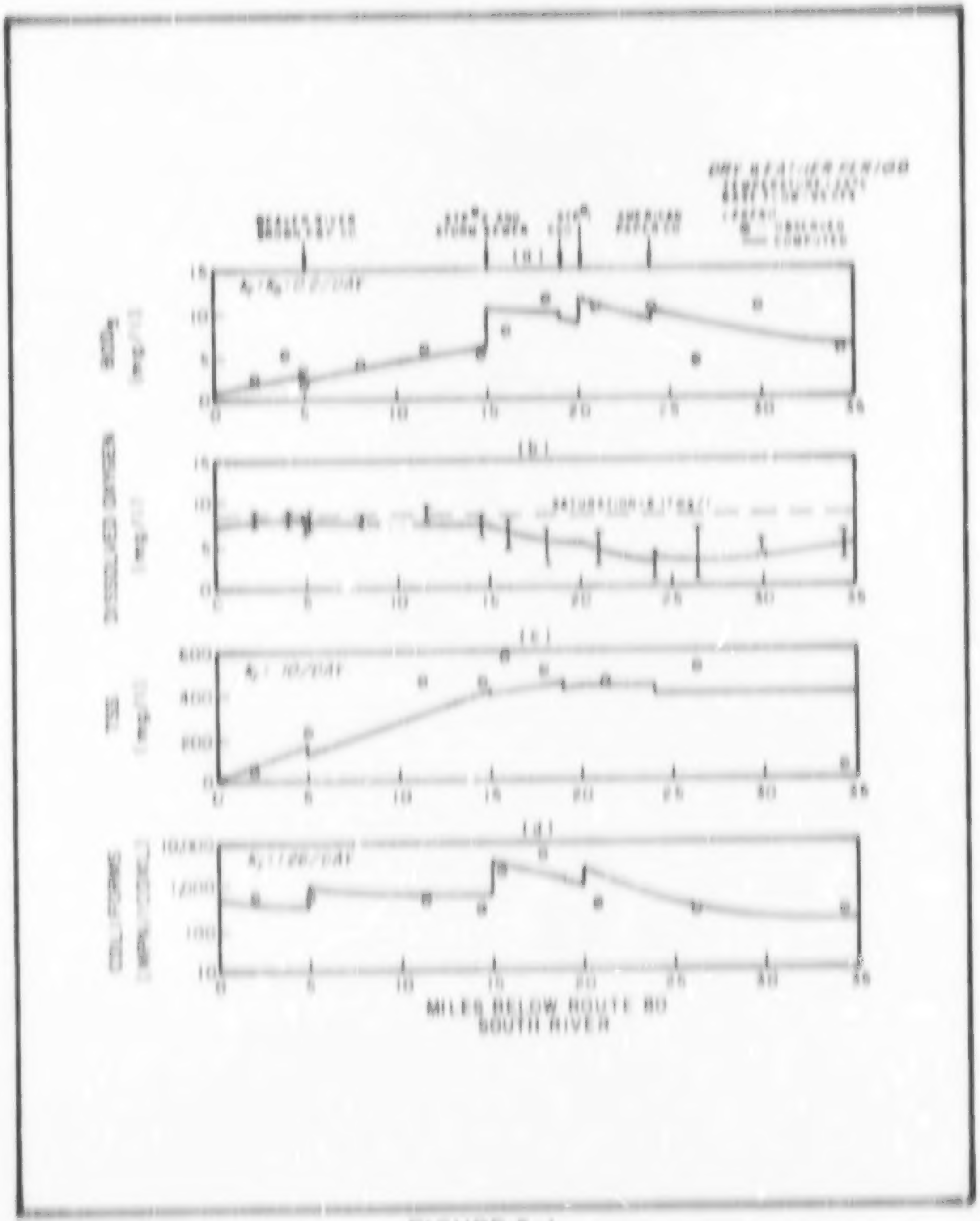


FIGURE 5-1
HYPOTHETICAL SOUTH RIVER-MODEL CALIBRATION ANALYSIS

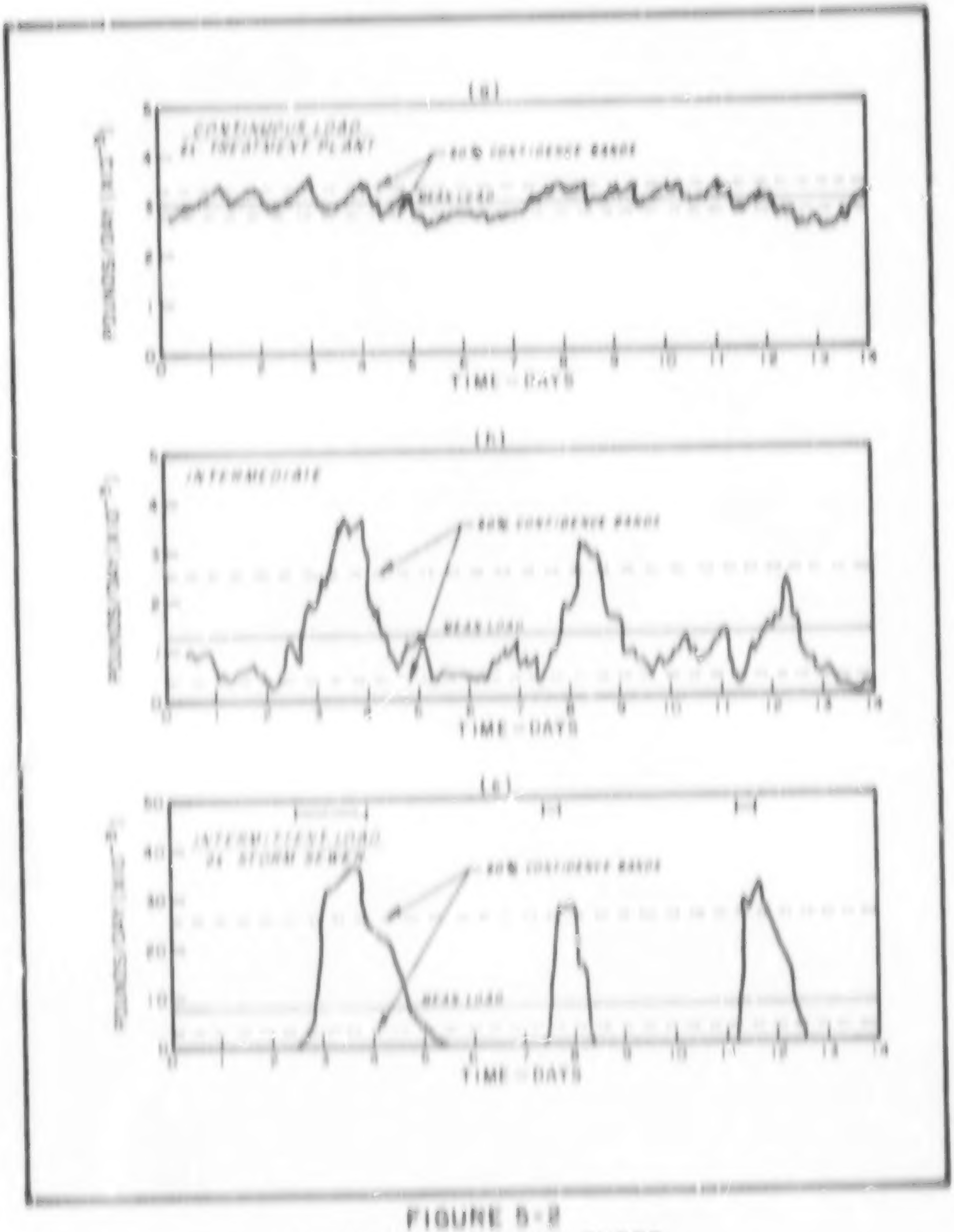


FIGURE 5-2
EXAMPLES OF LOAD TYPES

variability and must be evaluated on a case by case basis. In general the hydraulic capacity of the plant and the combined sewer system puts an upper limit on the load variability.

5.2.2.2 Intermittent Loads

The second category of time variable loads, the intermittent load, is characterized by an on-off type of behavior. Typical of this type of load is the loading from a storm water outlet. During dry periods, the discharge is zero, and during and immediately after the storm, a major pulse load occurs. Figure 5-2(c) typifies this behavior. Normally intermittent loads cannot be effectively treated as steady state. The loading is simply not sustained for a period of time which approaches the time-to-steady state in the receiving water. A number of water quality analysis techniques exist for evaluating receiving water responses to this type of pulse load. Most of these involve detailed time variable integrations of receiving water equations with detailed loading histories as inputs.

5.2.2.3 General Classification of Loads

Between the continuous and the intermittent loads is a spectrum of the time variable loadings which possess characteristics of both types. Typical of these loads are loadings from wastewater treatment facilities servicing combined sewer systems and industrial loads having high volumes of batch production. It is important for the engineer to analyse the load mix to a receiving water and segregate the various loads into steady state and time variable categories. Each loading type is treated differently in the water quality simulation analysis.

5.2.3 Stream Response Characteristics

The water quality response in streams varies depending upon the nature of the loading function. Stream response to continuous point and distributed sources is discussed in Chapter 2. Steady state responses to conservative, reactive and coupled system variables is given in that chapter. Time variable loads from continuous discharges and other intermittent loadings result in similar water quality responses. However, in this case, the response has an associated variability which is largely dependent upon the variability of the loading function.

In order to understand the relationship between load variability and water quality variations one can view the stream as a purely advective system, that is a plug flow system. If such a system is loaded with a series of pulse loads of a conservative tracer as indicated in Figure 5-3(a), measurements at a downstream point would yield a series of pulse responses as indicated in Figure 5-3(b). The time between the measured pulses and their magnitude would be directly related to the characteristics of the input loading function and the pertinent stream characteristics such as river flow, channel characteristics, etc.

In natural water systems, there is normally some longitudinal mixing taking place as the pulses move downstream. The effect of such mixing, or dispersion as it is commonly called, is to spread the pulses out as indicated in Figure 5-3(c). Dispersion in stream systems can be neglected where the time of travel is short. However, in other situations it is a factor in attenuating the response to discrete pulse loading events.

Analysis of the dispersion problem can be accomplished using the curve displayed in Figure 5-4. The Figure displays percent attenuation of the peak concentration as a function of travel time in the stream and the duration of the rainfall event. Steady state model responses can be adjusted accordingly to account for dispersion effects. A complete discussion of the theoretical basis for Figure 5-4 is contained in reference 3. Computer programs discussed in Appendix A can also be used to evaluate the problem further. In any event, methods presented in this manual will yield conservative water quality responses downstream of the point at which dispersion becomes a relevant factor. Dispersion in stream systems is included in the present analysis.

Chapter 3 described the statistical characteristics of intermittent load histories such as that displayed in Figure 5-3. The underlying density function was shown to be gamma distributed, having a mean, W_L, and a coefficient of variation, v_W. The coefficient of variation is defined

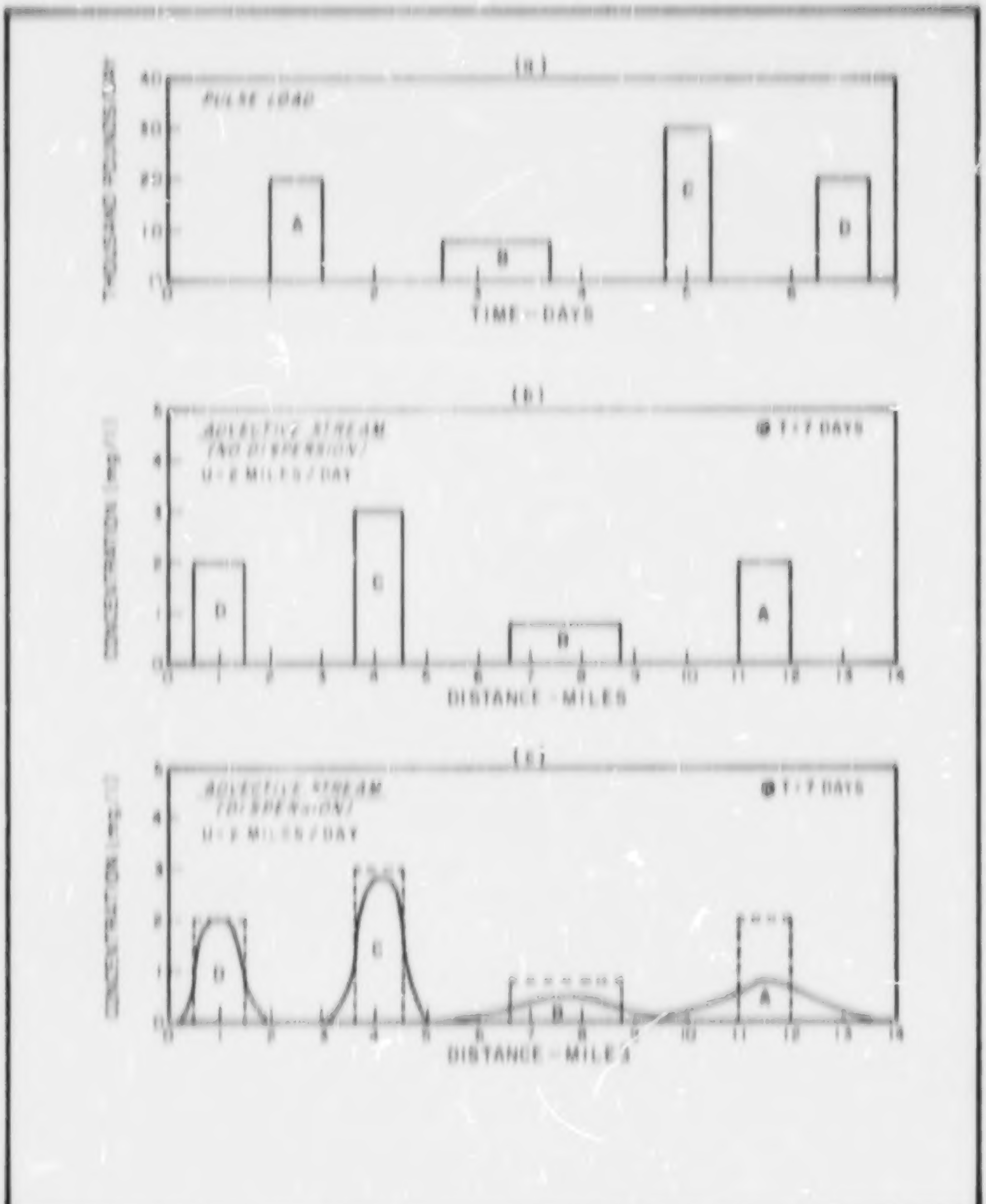


FIGURE 5-3
STREAM RESPONSE CHARACTERISTICS TO PULSE LOADS

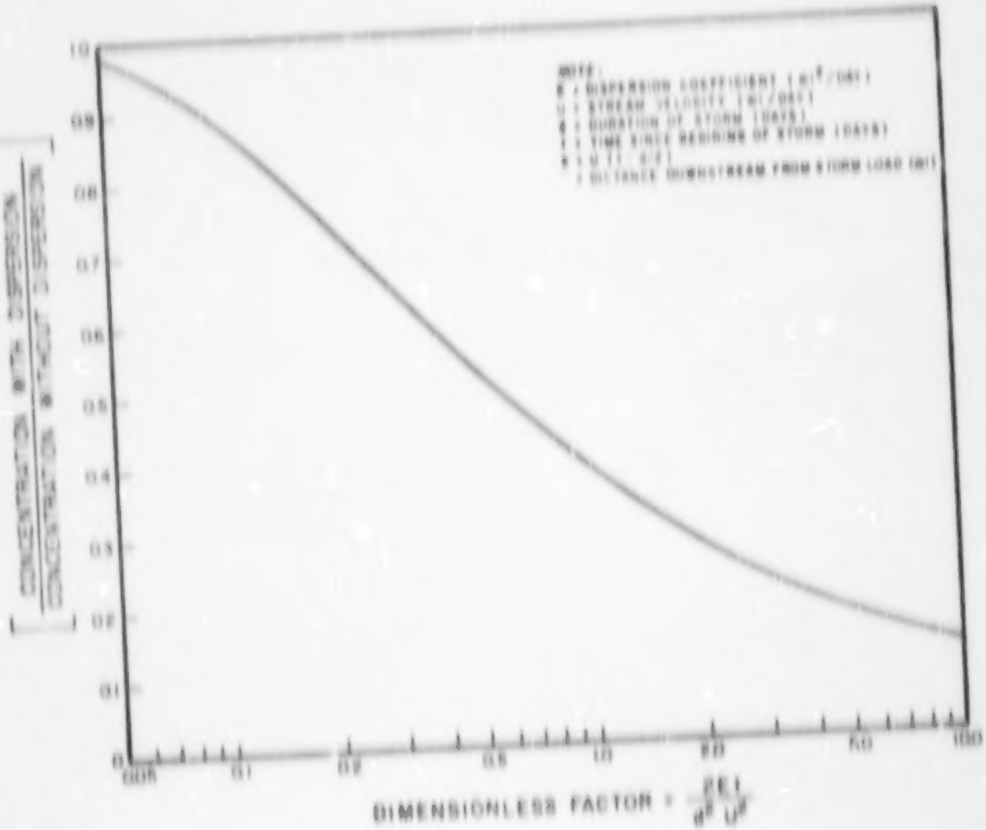


FIGURE 5-4
EFFECT OF DISPERSION ON POLLUTANT CONCENTRATION AT MIDPOINT OF STORM PULSE

as the standard deviation divided by the mean. The subscript w denotes that this is a statistic of the load W(t).

The analysis methods for evaluating in-stream water quality responses due to intermittent loads utilizes the statistics of receiving water quality due to that load. The behavior of the system can be thought of as analogous to the pulse load example presented in Figure 5-3, the difference being that instead of inputting a time history of discrete load events, the statistics of the history of those events is input to the stream model. The model then generates a statistical water quality response consisting of a mean and a standard deviation at all points downstream of the load. The frequency distribution of the water quality response is identical to that of the input load for the case of a single load or a closely grouped set of similar loads. For cases where there are numerous loads, all having different undefined density functions, the Central Limit Theorem suggests that the downstream water quality frequency distribution approaches a normal distribution. However, in cases where the spatial extent of the study area is small, and dominated by storm related loadings the underlying water quality frequency distribution is best described by that for the loads (i.e., a gamma distribution).(4)

The concept is shown diagramatically in Figure 5-5. Here two loads are shown: a continous steady state load and an intermittent load. The statistics of the loads can be generated using the methods presented in Chapter 3. The continuous load is characterized completely by its mean, $\bar{W}$, (Chapter 2), the intermittent load is characterized completely by its mean, $\bar{W}_I$, its coefficient of variation, v_w, and its distribution function.

The stream model shown in the Figure is the subject of discussion in the next section. It consists of the stream characteristics described in Chapter 2: channel geometry, reaction rates, and transport characteristics. Its function is to translate the load statistics from various sources into a water quality response having a computed mean and standard deviation. An alternate method for achieving similar results using empirical relationships is demonstrated in Section 5.3.4.

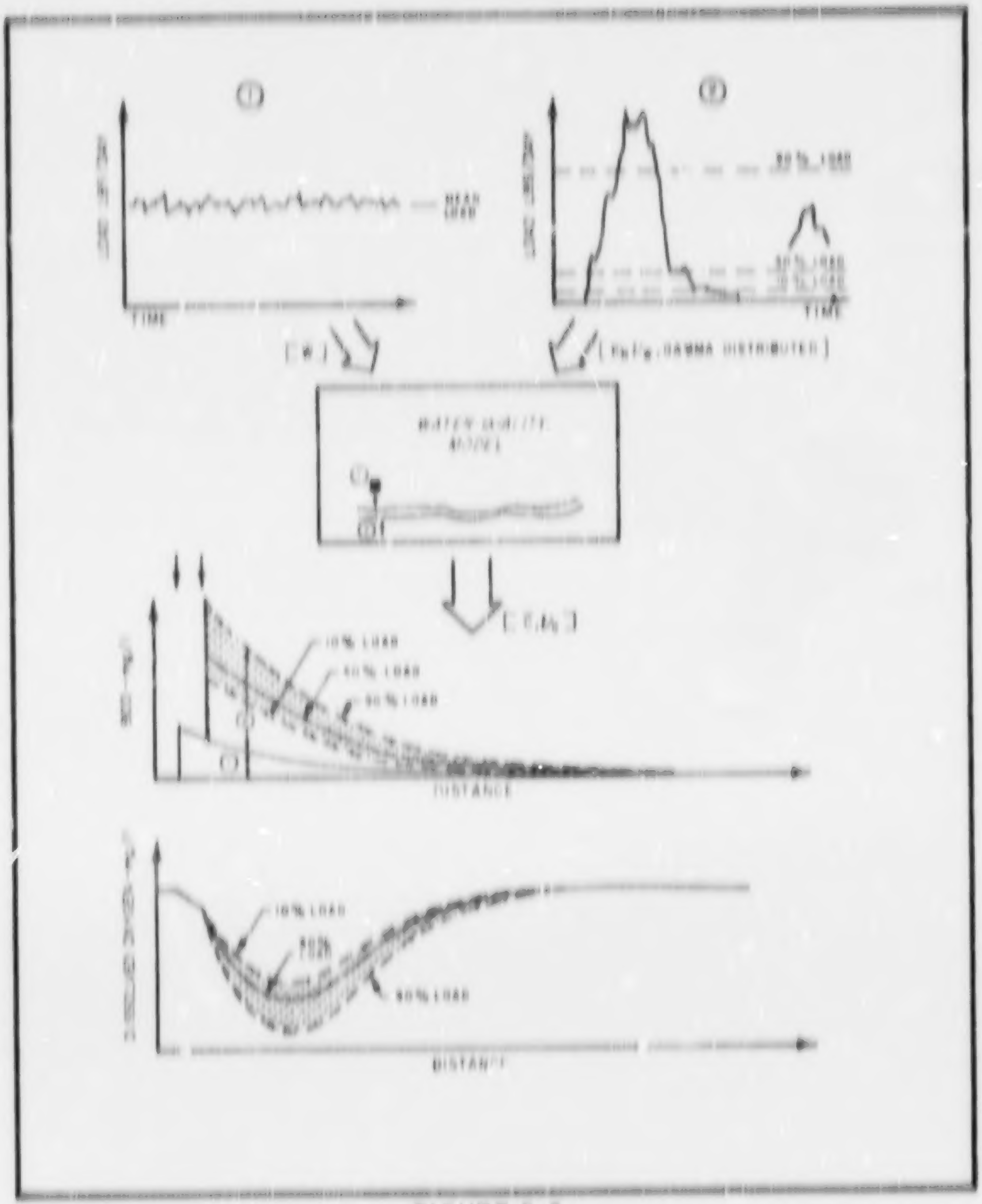


FIGURE 5-5
WATER QUALITY RESPONSE SIMULATOR
BOD-DISSOLVED OXYGEN EXAMPLE

5.2.3.1 Time Variable Water Quality Simulator

In Chapter 2 a summary of equations for computing pollutant concentrations in receiving waters are presented (Table 2-17, pg. 2-83). The reader is referred to Section 2.6.3.1 through 2.6.3.4 (pg. 2-82 to 2-97) for a detailed discussion of the coefficients in these equations.

In the special case of constant flow advective systems, the variability characteristics of the response function as a function of load variability are well known. In particular, it can be demonstrated that the coefficient of variation of the water quality response at any location is equal to the coefficient of variation of the input loads(5). That is:

$$v_c = \frac{\sigma c}{\hat{c}} = v_W = \frac{\sigma W}{\hat{W}} \qquad (5-1)$$

where: v_c, v_W are the coefficients of variation of concentration and load
σ_c, σ_W are the standard deviation of concentration and load
$\hat{c}$, $\hat{W}$ are the mean concentration and mean load.

Thus knowing the mean load and its variability one can compute the mean response using a steady state water quality model and then calculate the variability of the water quality response using the above relationships. This is a valid and recommended approach to analysing variable load impacts on streams where the constant flow assumption holds.

For example if one knows that a single point source has a mean load of 10^3 lb/day, a standard deviation of 10^2 lb/day, and a normal probability density function, it is a trivial problem to determine the mean load response and superimpose on that response a normal probability distribution having a coefficient of variation of 0.10. The 68% variability around the mean response in this case would be: $v_c \cdot \hat{c}$, or $0.1 \cdot \hat{c}$. This formulation only applies to constant flow systems.

However, in situations where intermittent loads such as storm related loads exist the impact of the load on the advective flow is often a major factor. Thus:

$$V_t \neq V_W$$

and other approaches must be developed. One such approach is presented in the example problem of Chapter 5. An alternative approach is presented in Reference (6).

As in Chapter 2, the unit response in water quality due to a single load to a linear system can be computed independently of all other loads. This is also true in the time variable simulator. However, a different set of ground rules must be established for combining the water quality responses due to a number of intermittent loads.

One base premise can be established: the water quality responses due to mean loads calculated from equations presented in Table 2-17 (eq. 2-83) are additive. That is the total mean water quality response is the sum of responses due to mean loads at all discharge points. However, the frequency distribution of the response function is normally not known even if the load frequency distributions are defined. Thus questions regarding expectations of water quality responses having specified levels are difficult to answer given the mean loads and their probability density functions.

The approach taken in this manual is one where the load statistics are developed in sufficient detail to permit statements regarding the expectation of various loads. The storm related loads are then interpreted in terms of the frequency with which they are expected to occur during wet weather (due to storms) and during longer term periods which include storms (i.e., season, year). The storm loads of given frequency and their associated flow are then used to compute water quality responses which will occur with approximately the same frequency as those loads. For example, if one determines that the 60% storm event (that which will be exceeded by only 40% of the storms) is a loading event which will only be exceeded 2% of the time, the water quality response due to that load is expected to occur with roughly the same frequency, 2% of the time. Within this analysis framework the storm related loads are expected to be correlated to a relatively high degree. That is, large storms cause correspondingly large loads at all wet weather discharges in an urban area.

The pollutant concentrations developed using this method will generally be within the accuracy of the level of stream analysis presented in this chapter. Methods for combining unit responses, discussed in Section 2.6.3.1, are appropriate within the context of Chapter 5.

5.2.3.2 Aggregating Loads for Representation as Point Sources

In some cases where a number of similar loads are located close to each other relative to the spatial scale of the water quality problem being modeled, it is possible, and in most cases desirable, to aggregate loads into a single point source. This treatment of loads simplifies the analysis with little effect on the accuracy of the calculated receiving water quality.

In general loads can be aggregated with no more than a 5% error in accuracy if they lie within a distance described by:

$$x \leq 0.05 \frac{U}{K} \qquad (5\text{-}2)$$

where: U = river velocity (miles/day)
K = first order reaction rate (per day)

For example, consider the carbonaceous BOD load distribution shown in Figure 5-6(a). If the river flow is estimated to be 10 miles/day and the first order BOD reaction rate is taken as 0.2 per day, the distance over which loads can be aggregated is 2.5 miles:

$$x \leq 0.05 \frac{(10)}{0.2} \leq 2.5 \text{ miles}$$

The resulting aggregated point source loads are shown in Figure 5-6(b). The basis for equation (5-2) is a simple computation which evaluates the equation for a first order reactive substance (Table 2-17 pg. 2-83) at the point where the discharge occurs and at a downstream point where the concentration has been reduced by 5%. Equation (5-2) results when the equations at the two points are subtracted.

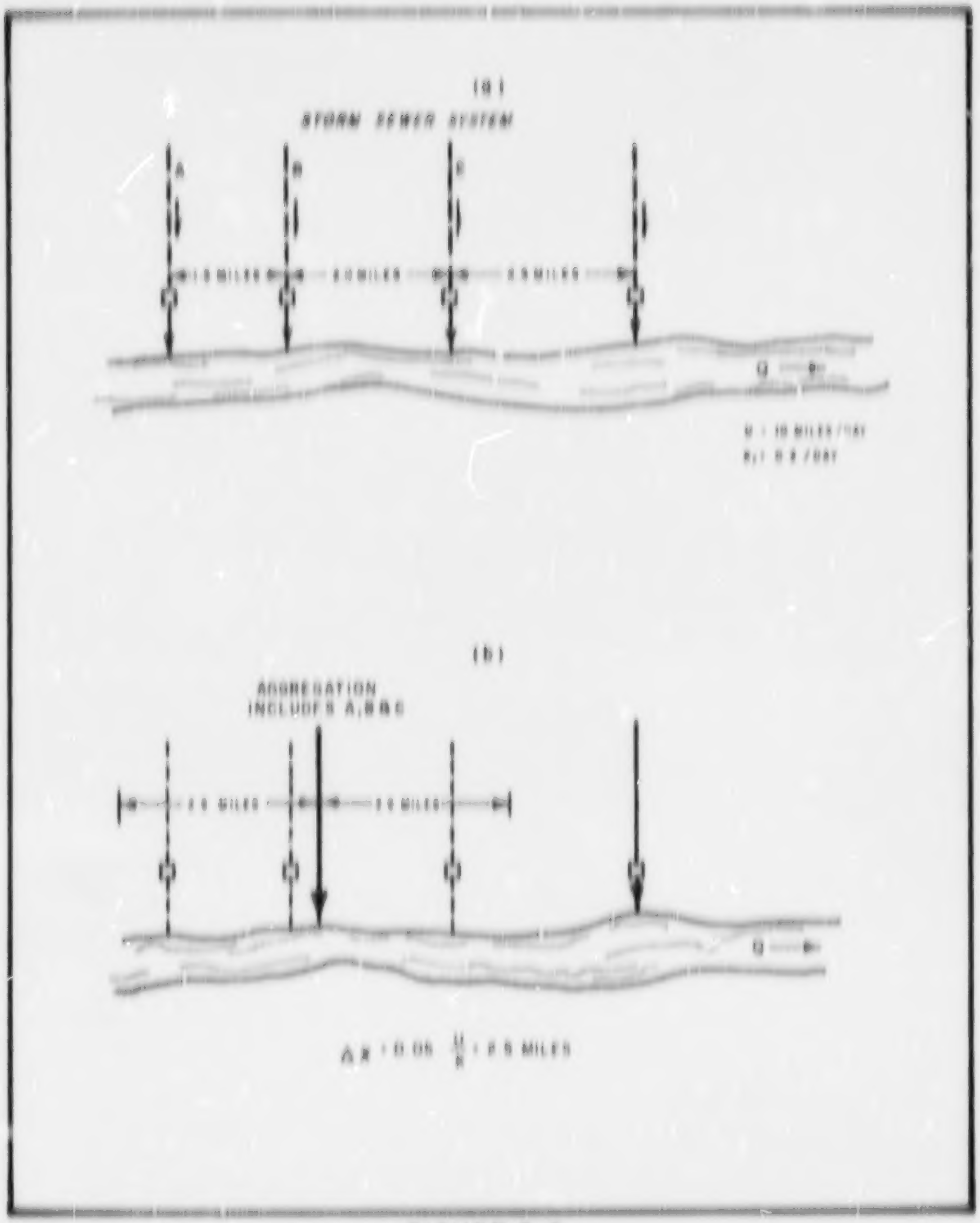


FIGURE 5-6
METHOD FOR AGGREGATING LOADS IN STREAMS

5.2.4 Application of Stream Impact Analysis Methods

Analysis methods presented thus far are illustrated in this section. The principal emphasis will be to apply the load generation techniques from Chapter 3 and the stream impact analysis methods discussed thus far in Chapter 5 in a typical 208 planning area setting. The hypothetical Jefferson City study area which was analyzed in a preliminary manner in Chapter 2 is used for this purpose.

Analysis methods demonstrated here are more detailed than those from Chapter 2. Some of the simplifying assumptions regarding urban land use, sewerage systems and river characteristics are replaced with detailed representations more consistent with study area characteristics which the 208 planner is likely to encounter. In addition, a set of realistic, but hypothetical, problem constraints are imposed to demonstrate a broader scope of planning problems and opportunities. While the example analysis is designed to be instructional in nature, it is site specific to the Jefferson City study area. Therefore the 208 planner should use the methodology behind the example as a pattern for structuring a water quality impact analysis in his specific study area. He should not simply attempt to reproduce the computations presented in this section in another study area.

As indicated above, the problem setting is basically the same as the Jefferson City South River problem setting from Chapter 2. The following modifications are instituted, however, to make the study area more realistic:

1. The urban area is described in terms of its major land use classifications.
2. A second treatment plant is included at an upstream location.
3. The major features of the sewer systems are described.
4. A water treatment plant is located above the city.
5. A realistic set of population projections are developed.

These details are presented in Section 5.2.4.1.

5.2.4.1 Problem Setting

The hypothetical Jefferson City is located on the South River (Figure 2-5 pg. 2-18). The urban area consists of two sewer districts designated Sewer District No. 1 and Sewer District No. 2. These are shown in Figure 5-7. District No. 1 located on the north side of the River has a 20 year old combined sewer system which services an area of 8,000 acres. A primary wastewater treatment plant having an average daily design capacity of 9 MGD services the area. The plant is presently operated at its full design capacity. Present plans are to convert this plant to a secondary treatment facility within the planning period. Both the combined sewer system and the plant have a peak hydraulic capacity of 36 MGD. Combined sewer overflow regulators bypass excess flows to the South River at three locations indicated in the figure.

Projected land use types within sewer District No. 1 at the end of a 20 year planning period are shown in Figure 5-8. The area is an established urban area having a central commercial district surrounded by light industry and residential housing. Industrial wastewaters are presently collected at a central location and pumped untreated to the primary treatment plant through a force main.

Sewer District No. 2 was constructed 10 years ago to service the rapidly growing area to the west and south of the central City. Development style housing and a new commercial district contribute to low to moderate population density within this area at present. Planning projections for the area indicate a trend toward more dense residential housing in the future. Figure 5-8 shows the projected land use patterns. A separate sanitary sewer system services the district and conveys treated wastewaters to a secondary treatment plant at the west end of the City. A force main conveys sanitary wastewaters from the south side of the South River to the plant which has an average daily design capacity of 12 MGD. The plant presently treats 11 MGD. A storm sewer system services District No. 2. Its design capacity is in excess of 900 MGD. Overflows operated by weir type regulators are activated by excess flows.

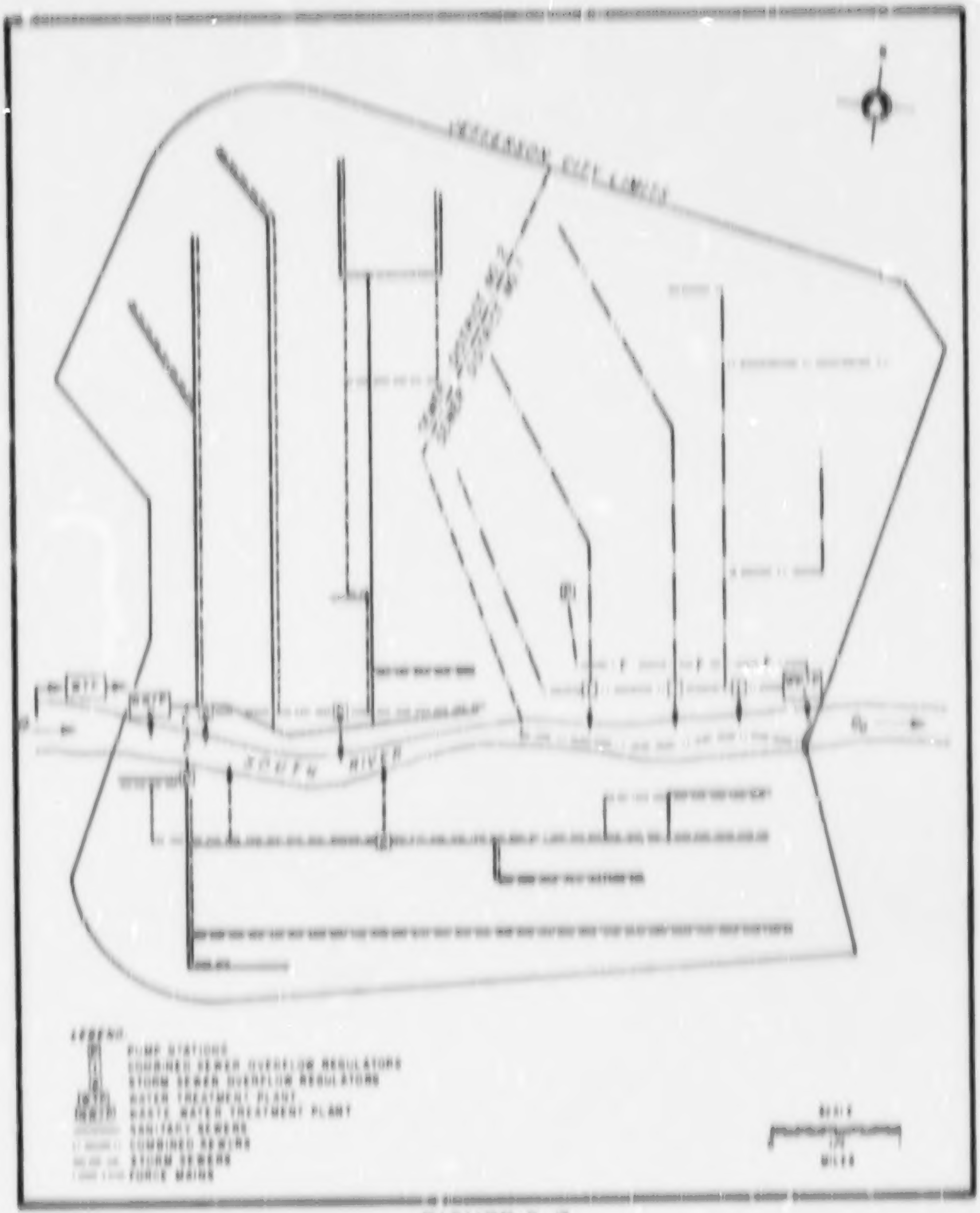


FIGURE 5-7
JEFFERSON CITY STUDY AREA
COLLECTION SYSTEM

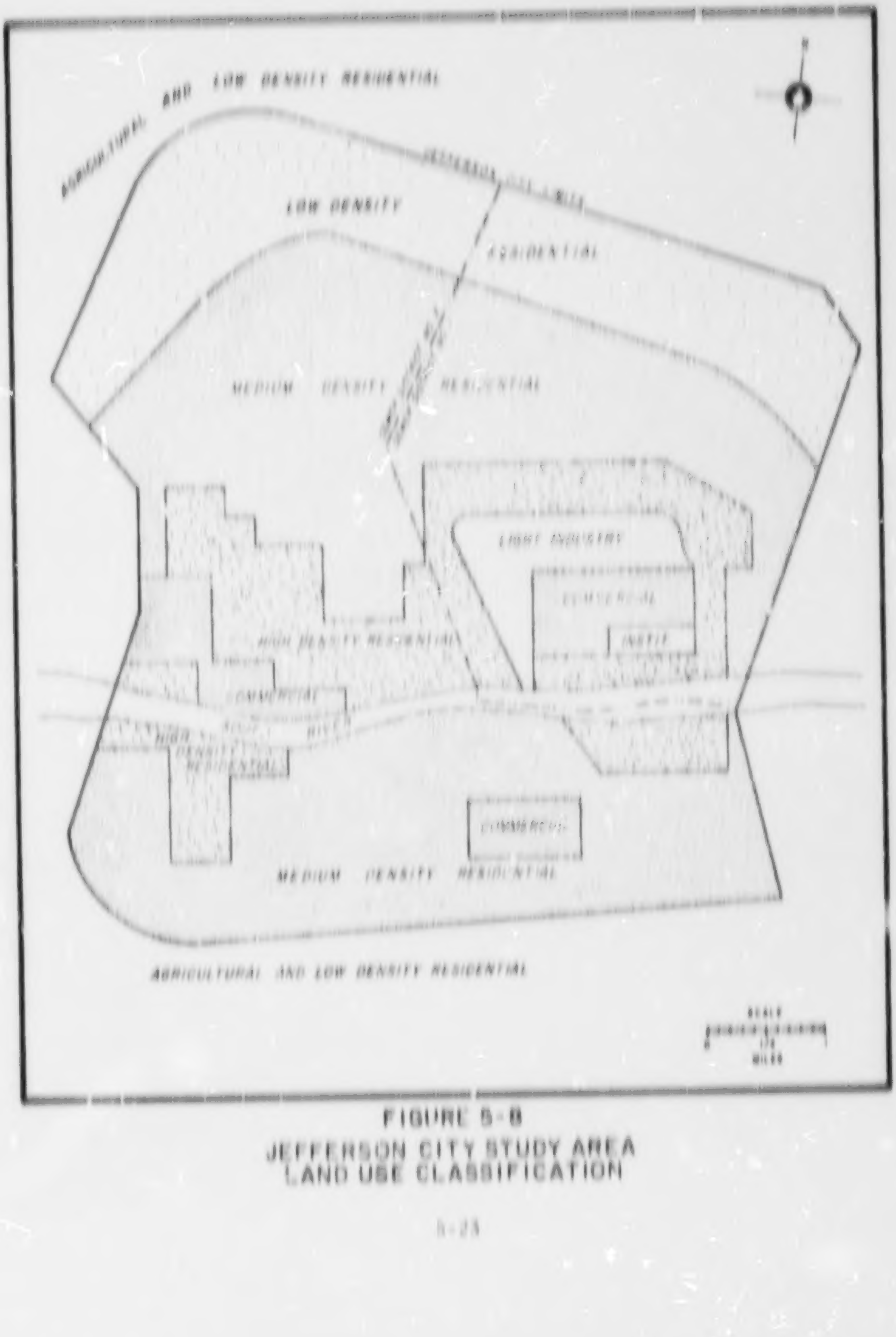


FIGURE 5-8
JEFFERSON CITY STUDY AREA
LAND USE CLASSIFICATION

A water treatment plant having a design life of 30 years was just constructed in a rural area west of town to service Jefferson City. The entire water supply for the City is withdrawn from the South River at this point.

Continued growth is expected throughout the urban-suburban area. Recent population studies conducted as part of the water supply plan are displayed in Figure 5-9. The population figures have been reworked along sewer district boundaries. In general, District No. 1 is expected to have only moderate growth during the next 25 years, while District No. 2 is expected to increase in population by between 35 and 110 percent.

5.2.4.2 Load Estimation

Load estimates for the Jefferson City study area are generated in a preliminary fashion in Chapter 2. The reader is referred to that chapter and the load generation techniques in Chapter 3 for specific details which are not repeated here. Non-urban loads from upstream and surrounding forest and rural areas are derived from Chapter 2.

The rainfall characteristics in the hypothetical South River Basin are taken as those for U.S. Weather Bureau Station 052220 displayed in Figure 3-15 (pg. 3-60). Two periods are considered in this chapter: the average summer storm condition (June through September), and the period of peak storm intensity, July. The rainfall characteristics during these two periods are displayed in Table 5-1.

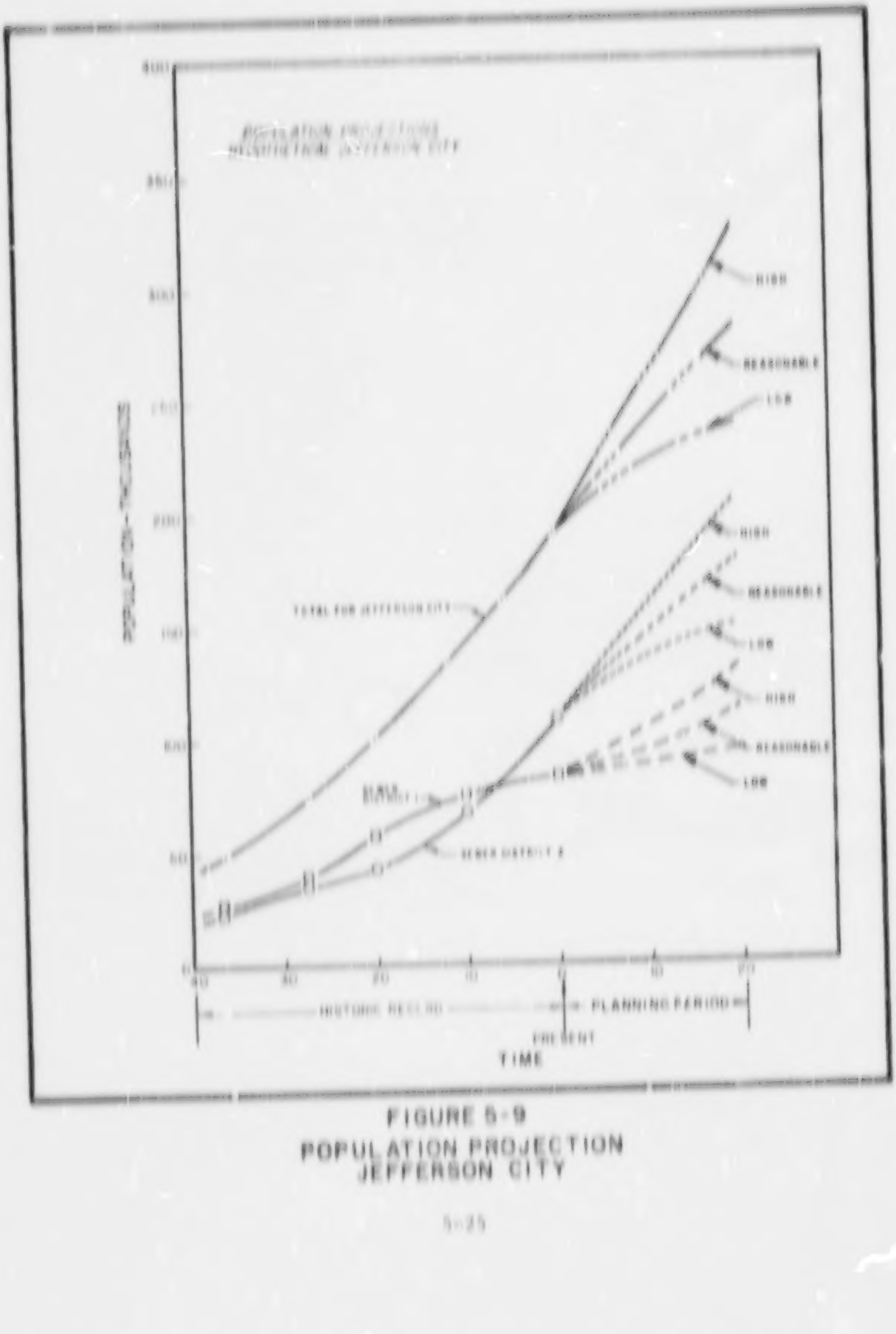


FIGURE 5-9
POPULATION PROJECTION
JEFFERSON CITY

TABLE 5-1

RAINFALL CHARACTERISTICS
HYPOTHETICAL SOUTH RIVER STUDY AREA

(a) SUMMER STORM PERIOD - JUNE THROUGH SEPTEMBER

Characteristic	Mean	Variation
Storm Intensity	$I = 0.055$ in/hr	$v_i = 1.55$
Duration	$D = 3.0$ Hrs.	$v_d = 1.15$
Volume	$V = 0.18$ in	$v_V = 1.00$
Time Between Storms	$\Delta = 80$ Hrs.	$v_\Delta = 1.15$

(b) JULY STORM PERIOD

Characteristics	Mean	Variation
Storm Intensity	$I = 0.062$ in/hr.	$v_i = 1.50$
Duration	$D = 2.5$ Hrs.	$v_d = 1.00$
Volume	$V = 0.17$ in	$v_V = 1.20$
Time Between Storms	$\Delta = 70$ Hrs.	$v_\Delta = 1.20$

Projected land use classifications within the two sewer districts for the 20 year planning period are displayed in Table 5-2. The information in this table was developed by the 208 study program and indicates anticipated land use classifications 20 years in the future. The total land area in District No. 2 is twice that for District No. 1. Both districts are expected to be dominated by medium density housing.

TABLE 5-2

LAND USE CLASSIFICATION IN THE HYPOTHETICAL JEFFERSON CITY
(Based on Population and Land Use Projections)

Classification	S. D. No. 1 Area (Acres)	S. D. No. 1 %	S. D. No. 2 Area (Acres)	S. D. No. 2 %	Total Area (Acres)	Total %
Low Dens. Hous.	2,120	26.6	2,640	17.6	4,760	20.7
Med Dens. Hous.	2,800	35.1	8,800	58.6	11,600	50.5
High Dens. Hous.	1,600	20.0	2,640	17.6	4,240	18.4
Commercial	540	6.8	940	6.2	1,480	6.4
Institutional	120	1.5	-	-	120	0.5
Light Industry	800	10.0	-	-	800	3.5
Totals	7,980	100.0	15,020	100.0	23,000	100.0

Using the methods described on page 3-30 the percent imperviousness of the urban area within the two sewer districts is computed to be:

Sewer District No. 1 - 40.9% impervious
Sewer District No. 2 - 42.5% impervious

The runoff coefficients for the two Districts developed from Figure 3-8 are:

Sewer District No. 1, C_v = .45
Sewer District No. 2, C_v = .47

These are in agreement with the value of 0.42 developed in the preliminary assessment (pg. 2-50 and Figure 2-15).

Runoff from the study area for the storm periods described in Table 5-1 are computed using methods from Section 3.4.3.2. A sample analysis of this type is presented on pages 3-59 and 3-60. The anticipated probability distribution of runoff flows 20 years in the future are presented in Table 5-3.

TABLE 3-3

RUNOFF FLOW, $Q_R = C_V IA$
(IN CUBIC FEET PER SECOND)
20 YEARS IN FUTURE

% of Storms Less Than	Multiple of the mean Factor	S. D. No. 1		S. D. No. 2	
		Summer Storms	July Storms	Summer Storms	July Storms
20	(.10)	20	23	39	44
50(MEAN)	(0.4)	79(198)	93(233)	155(388)	175(437)
75	(1.4)	277	326	543	611
90	(2.7)	535	602	1048	1180
95	(3.9)	772	870	1513	1704

where: $v_q = v_i$ = 1.55 for the average summer storm condition;
v_i = 1.50 for the peak intensity storm period, July;
The factor is the multiple of the mean from Figure 3-11b for v = 1.55.
( ) = The mean runoff flow in cfs calculated using Equation 3-15.

The product of the factor and the mean flow yields the runoff flow having the indicated probability. For example the 75% runoff from Sewer District No. 1 in July is 1.4 (233) = 326 cfs.

The loads associated with these flows can now be computed using methods presented in 3.4.3.3 and demonstrated on pages 3-60 through 3-62. In general pollutant concentration is assumed to be independent of flow, an adequate assumption in the absence of site specific data. That is, the mean concentration during storm events is only weakly correlated to the mean flow during that event. However, best engineering practice is to obtain measurements of pollutant concentrations at various storm water flow conditions and verify concentration-flow independence on a site specific basis. In cases where significant long term correlations do exist, an appropriate adjustment to the analysis procedure would have to be made.

the basic data for computing the storm loads for the hypothetical Jefferson City urban area are contained in Table 5-3. Without a correlation for the specific site between the concentration and total runoff flow, the variability of the flow and concentration cannot both be used as in equation 3-30 to determine the variability of the load. The correlation between concentration and runoff flow is not known on the South River. The coefficient of variation for the loads from the two storm conditions are, therefore, taken as the coefficients of variation of the runoff flow. That is, it is assumed that concentration is essentially constant from event to event and:

Average summer storm condition; $v_W = 1.55$
July storm condition; $v_W = 1.50$

The assumption of constant concentration appears to be an acceptable simplification based on data collected in numerous U.S. cities. However, an alternative procedure which includes observed variability in concentration is presented on page 3-62 and can be applied where the flow-concentration relationships are available from an observed data base. The loads from intermittent sources in the South River study area are displayed in Table 5-4.

Point source loads from the two municipal wastewater treatment plants in Jefferson City are expected to increase during the planning period. The loadings are developed from the "reasonable" set of population projections assuming the same treatment as presently exists at expanded treatment facilities in Sewer District No. 2, and upgrading of the Sewer District No. 1 plant to at least secondary treatment. The loadings from both plants are estimated in Table 5-5. For example, in Sewer District No. 1, the total nitrogen load using the reasonable population projections (Figure 5-9) is computed as: $w = 20\ \text{mg/l} \times 10^{-6} \times 8.34 \times 1.12 \times 10^{5}$ people $\times 150$ gpc/day = 2818 lbs/day. Tributary and industrial loads are those presented in Chapter 2.

TABLE 5-4

SUMMARY OF STORM RELATED LOADS TO THE HYPOTHETICAL SMITH RIVER

(1) BOD_5 Load[a] - (Thousand Pounds/Day)

% of Storms Less Than	Factor[b]	S.D. No. 1 Summer Storm	S.D. No. 1 July Storm	S.D. No. 2 Summer Storm	S.D. No. 2 July Storm
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50(Mean)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[a] [illegible] mg/l, separate storm sewer - District #1. [illegible] mg/l, combined sewer - District #1.

[b] Factors are from Figure [illegible].

(2) Total Coliform Load[c] [illegible] MPN/Day)

% of Storms Less Than	Factor[d]	S.D. No. 1 Summer Storm	S.D. No. 1 July Storm	S.D. No. 2 Summer Storm	S.D. No. 2 July Storm
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50(Mean)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[c] [illegible] MPN/100 ml, separate storm sewer - District #1. [illegible] MPN/100, combined sewer - District #1.

[d] Factors are from Figure [illegible].

(3) Total Nitrogen Load[e] - (Thousand Pounds of N/Day)

% of Storms Less Than	Factor[f]	S.D. No. 1 Summer Storm	S.D. No. 1 July Storm	S.D. No. 2 Summer Storm	S.D. No. 2 July Storm
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50(Mean)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[e] [illegible] mg N/l, separate [illegible] sewer - District #1. [illegible] mg N/l, combined sewer - District #1.

[f] Factors are from Figure [illegible].

(4) Total Phosphorus Load[g] (Thousand Pounds of P/Day)

% of Storms Less Than	Factor[h]	S.D. No. 1 Summer Storm	S.D. No. 1 July Storm	S.D. No. 2 Summer Storm	S.D. No. 2 July Storm
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50(Mean)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[g] [illegible] mg P/l, separate [illegible] sewer - District #1. [illegible] mg P/l, combined sewer - District #1.

[h] Factors are from Figure [illegible].

(5) Total Suspended Solids Load[i] - (Thousand Pounds/Day)

% of Storms Less Than	Factor[j]	S.D. No. 1 Summer Storm	S.D. No. 1 July Storm	S.D. No. 2 Summer Storm	S.D. No. 2 July Storm
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50(Mean)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
95	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[i] [illegible] mg/l, separate storm sewer - District #1. [illegible] mg/l, combined sewer - District #1.

TABLE 5-5

MUNICIPAL TREATMENT PLANT LOADS - 20 YEARS IN FUTURE
HYPOTHETICAL JEFFERSON CITY

		Total Nitrogen		Total Phosphorus		Total S.S.	
Discharge	Flow	mg/l	lbs/day	mg/l	lbs/day	mg/l	lbs/day
S.D. #1 plant	16.9	20	2818	10	1409	19.8	2791
S.D. #2 plant	30.4	20	5070	10	2535	19.8	5020

* *

		BOD_5		Total Coliforms	
Discharge	Flow	mg/l	lb/day	No./100 ml	No./day
S.D. #1 plant	16.9	30	4228	1000	6.4×10^{11}
S.D. #2 plant	30.4	30	7606	1000	1.1×10^{12}

5.2.4.3 Stream Impact Analysis Conditions

The first step in the stream impact analysis is to reverify the conclusions resulting from the preliminary assessment procedures presented in Chapter 2. Those conclusions are summarized in Table 2-26. It is possible that the reestimation of loadings could significantly change one or more of these conclusions.

This task is accomplished by simply repeating the analysis for present and projected loading conditions and verifying that the water quality responses resulting from the more refined loads and the statistical water quality analysis methods of Chapter 5 lead to the same conclusions regarding the probability of potential problems. This of course, assumes that the basic water quality model has been adequately calibrated to the specific site at least for steady state conditions as discussed in Section 5.2.1.

Bottom demands are not included in the South River example. It should be pointed out that many problem cases will have significant dissolved oxygen water quality impacts because of bottom demands. In these cases the analysis framework can be extended to include bottom effects by including bottom demand terms in the equations displayed in Tables 2-17 as discussed in Section 5.5 and illustrated in Table 5-21.

The procedure for applying the time variable water quality method using the statistical loads is illustrated in this section. Because of space limitations a complete set of analyses for the South River will not be developed. Rather, a selected group of problem cases will be analyzed to demonstrate techniques in applying the statistical water quality method and interpreting its outputs. Toward this end, the method application to reverify the conclusions generated in Chapter 2 is omitted and the analysis focuses on the specific problem cases outlined in Table 5-6.

TABLE 5-6

CRITICAL WATER QUALITY CONDITIONS
HYPOTHETICAL SOUTH RIVER

	Water Quality Indicator			
River Flow Condition	Dissolved Oxygen	Sanitary W.Q.	Eutrophication	Suspended Solids
Drought flow	X			
Average summer flow			X	
Peak summer storm flows	X	X		X

Table 5-6 indicates flow conditions for which specific water quality problems will be analyzed. Dissolved oxygen concentrations in the Chapter 2 analysis were shown to be critical during drought flow conditions and during peak storm runoff conditions. The point sources dominated the drought flow response while combined sewer overflows were a principal contributor to the low dissolved oxygen during storm periods. Sanitary water quality problems were maximum during peak storm conditions. The combined sewer overflows contributed a major portion of the loading in this case. The preliminary eutrophication analysis indicated probable water quality problems during long term average loading conditions indicative of the average summer flow condition. The possible suspended solids problem case is reanalysed in this chapter during wet weather periods when urban non-point sources are significant.

The reader should note that the South River study area has been modified somewhat in Chapter 5 to make the example more illustrative. Therefore, water quality responses in the River are expected to be different than those presented in Chapter 2. In addition, the analyses presented here represent conditions 20 years in the future. Therefore, land use types, loadings and river flows developed for future conditions (Sections 5.2.4.1 and 5.2.4.2) are applied in the analysis. Subsequent analysis in Chapter 6 will deal with load allocation techniques, control practices and methods for developing minimum cost solutions to the principal water quality problems.

Existing combined sewer overflow loads from Jefferson City are located at Milepoints 18.5, 19.0 and 19.5, as shown in Figure 5-7. Rather than treating these loads as a uniformly distributed load from Milepoint 15 to Milepoint 20, as was done in Chapter 2, it is reasonable to combine these three discrete point source loads into one point source load located at Milepoint 19, using the criteria presented in Section 5.2.3.3, equation(5-2). Assuming it is desired to maintain an accuracy of approximately 5% when aggregating these loads, it is only necessary to check that the loads are within a distance x given by: $x \leq 0.05\ U/K$. Information contained in Tables 2-3 (pg. 2-34) and 2-16 (pg. 2-81) can be used to determine the river velocity within segment 3 at the lowest flow condition for which the combined sewer overflows contribute a loading to the analysis. The summer average flow satisfies this criteria in that the time averaged combined sewer overflow load is used in this analysis. The river velocity for this period is computed to be 8.48 miles per day. Therefore, loads within $x \leq 0.05\ (8.48)/0.20 \leq 2.1$ miles can be aggregated in computing BOD-dissolved oxygen responses in the South River. The BOD decay rate of 0.18 per day developed in the calibration analysis has been temperature adjusted to 25^{0}C using equation (2-7)(pg. 2-87) in this computation. Hence, it is justifiable to locate the three CSO loads at Milepoint 19 without causing a significant change in the results of this analysis. An additional segment beginning at Milepoint 19 is added to the stream in order to input the load at this location. The segment characteristics are the same as those for segment 3.

The urban runoff load from portions of Jefferson City located within Sewer District No. 2, which was treated as a uniformly distributed load in Chapter 2, will also be treated as a point source load in this example, located at Milepoint 15 as shown in Figure 5-12. The hypothetical South River example now includes 6 constant parameter segments, bounded at Milepoints 0, 5, 15, 19, 20, 24 and 33. A summary of the geometry for the revised model segmentation is developed from Table 2-3(b) (pg. 2-34).

Another consideration is the impact of increasing populations during the planning period and the consequent impact on stream flows within the study area. This effect is minimal in the case of Sewer District No. 2 where the wastewater discharge is immediately below the water intake point. The only difference in flow in the case is consumptive loss which can generally be estimated as 10% of the raw water intake flow. This flow difference is estimated to be 3 cfs.

$$Q_{loss} = .1\ (180{,}000\ \text{people}) \times 110\ \frac{\text{gallons}}{\text{person/day}} \times 1.54 \times 10^{-6}\ \frac{\text{cfs}}{\text{gpd}}$$

$$Q_{loss} = 3.05\ \text{cfs}$$

The population increase in sewer District No. 1 is estimated to be 19,000 people. Thus the withdrawal flow is estimated to be:

$$Q_{SD1} = 19{,}000\ \text{people} \times 110\ \frac{\text{gallons}}{\text{person/day}} \times 1.54 \times 10^{-6}\ \frac{\text{cfs}}{\text{gpd}}$$

$$Q_{SD1} = 3.2\ \text{cfs; say 3 cfs}$$

Ninety percent of this flow is reintroduced at Milepoint 20. The resulting drought flow conditions in the river are summarized in Table 5-7.

TABLE 5-7

FUTURE DROUGHT FLOW CONDITIONS IN THE HYPOTHETICAL SOUTH RIVER

Segment	Milepoints	Chapter 2 Flows(1)	River Flow (cfs) Change	Average Drought
1	0- 5	54	-	54
2	5-15	91	-	91
3	15-19	(101)	-6	95
4	19-20	103	-	97
5	20-24	109	+3	106
6	24-33	116	-	113

(1)Table 2-16, (pg 2-81)

5.2.4.4 Computing Water Quality Response Frequency

The frequency with which extreme water quality events will occur due to intermittent loads is generally considered to be a joint probability function incorporating factors such as rainfall intensity and duration, storm water flow concentrations, the interval between storms, and a number of receiving water characteristics such as base flow, temperature, and background concentration. Simplifying assumptions which are based in part on observations and in part on intuitive reasoning are developed in this section to arrive at a best estimate of the relationship between storm related load frequency and the frequency of extreme water quality responses.

One can show that the percent of time that rainfall occurs is simply D/Δ since $\sum_i d_i/\Delta_i$ is the total duration of all rainfall events divided by the total time over which the record was gathered. Consider the rainfall characteristics for the South River shown in Table 5-1(a). The percent of time that rainfall occurs is estimated as:

$$P_r(I > 0) = D/\Delta = (3.0/80) \cdot 100 = 3.75\%$$

and the period without rain is:

$$P_r(I = 0) = 100 - P_r(I > 0) = 100 - 3.75 = 96.25\%$$

The probability that a storm related load, W_r, is less than or equal to a given value is estimated using the following equation.

$$P_r(W_r \leq W) = P_r(I = 0) + P_r(I > 0) \cdot P_r(W_r \leq W) \qquad (5\text{-}3)$$

This simply states that the probability that a storm related load is less than or equal to a value, W, is estimated as the probability of not experiencing rainfall, plus the joint probability of experiencing rainfall having a load less than or equal to W. For example, to compute the probability associated with a load which is only exceeded 1% of the time in the South River example:

$$P_r(W_r \leq W) = (100\% - 1\%) = 0.99$$

$$P_r(I = 0) = 0.9625$$

$$P_r(I > 0) = 0.0375$$

$$P_r(W_r \leq W) = \frac{0.99 - 0.9625}{0.0375} = .73$$

That is, the 99% load (that which is only exceeded 1% of the time), W, to the river is the load associated with the 73% storm event. Similarily the 1.5%, 2% and 3% loads can be shown to be associated with the 60%, 46% and 20% storm loads.

A major difficulty in defining statistical loads occurs when two variables (flow and concentration) are varying. The dilemma is one in which the probability of the loading event being exceeded is fixed and the analyst must determine the associated flow.

$$P_r(W_r \leq W) = P_r(c_r Q_r \leq W) \qquad (5\text{-}4)$$

If for example, the probability of a given load being exceeded is 30%, ($P_r(W_r \leq W) = .70$), a wide range of flow-concentration combinations exist which satisfy equation(5-4). The approach to the problem taken in this manual is to assume the concentration associated with the storm event constant, and associate all of the load variability with flow. Therefore, $P_r(W_r \leq W) = P_r(Q_r \leq Q)$. These methods are intended to be for guidance purposes only and can be modified to reflect local conditions and site specific observations regarding the relationship between flow and concentration between storm events.

5.2.4.5 Application to South River Water Quality

Equation(5-1) stated that in cases where the river flow is constant the coefficient of variation of the response function for a particular load is a constant for all distances downstream in a river, and is equal to the coefficient of variation of the point source wastewater input. This is not, however, the case in the South River where storm related runoff events have a significant impact on the stream flow.

The 20%, 50% and 75% storm loads are used to illustrate receiving water responses in this section. These loads are computed to occur 3%, 2% and 1% of the time from equation(5-3). For the urban runoff loading, which has a coefficient of variation of between 1.50 and 1.55 (Section 5.2.4.2), the 75% load is a factor of 1.4 times the mean loading (Table 5-4). The response due to the 75% load may therefore be computed by multiplying the mean load by the constant factor, 1.4, and by performing the analysis as illustrated in Table 2-20 (pg. 2-90) and 2-21 (pg. 2-95) using this load.

Table 5-8 presents an example calculations for the BOD response in the South River during the peak summer storm period using the former technique. The computation begins at segment 3 and illustrates the manner in which the 20%, 50%, and 75% profiles due to the variable load and the constant wastewater treatment plant load may be computed. The average flow, cross-sectiocal area and stream velocity are first determined, as well as the appropriate temperature adjusted reaction rate. The initial concentration due to the upstream sources (L_0) is then calculated from a mass balance at the beginning of the segment.

The variable storm sewer runoff load and the constant wastewater treatment plant load is entered at the appropriate probability levels desired, here, the 20%, 50% and 75% levels for the storm sewer and the average daily load for the treatment plant. Substitutution of these values into the solutions presented in Table 2-17 (pg. 2-83), results in a spatial

TABLE 5-8

REACTIVE CONSTITUENT (BOD_5) SAMPLE IMPACT CALCULATION
AVERAGE SUMMER FLOW - HYPOTHETICAL SOUTH RIVER EXAMPLE

Segment 3 : Milepoints [illegible]

[illegible] (Tables [illegible])

[illegible]

[illegible]

[illegible]

[illegible] BOD_5 = [illegible] mg/l

[illegible] mg/l [illegible] (Table [illegible])

[illegible] lb/day (Table [illegible])

[illegible] lb/day (Tables [illegible])

[illegible] (Table [illegible])

Applying Equation [illegible] of Table [illegible] with conversion factors for units:

[illegible]

For RP [illegible]: [illegible]

[illegible]

[illegible] mg/l

For RP 19: [illegible]

[illegible]

[illegible] mg/l

Since the storm sewer load is a transient load, [illegible] mg/l overestimates the expected response at RP 19. Dispersion will diminish the response due to the storm sewer load in the manner shown in Figure 5-4. This effect may be included by considering the [illegible] due to the storm sewer load alone, both with and without dispersion.

In this case:

[illegible] mi^2/day

[illegible] days

[illegible]

[illegible] mi/day

[illegible] days

and [illegible]

From Figure 5-4, $\frac{\text{Concentration with dispersion}}{\text{Concentration without dispersion}}$ = [illegible]

The response at RP 19 due to the storm sewer, without dispersion, is given by:

[illegible] mg/l

The concentration with dispersion = [illegible] mg/l.

The difference, [illegible] mg/l is the amount by which dispersion will reduce the response due to the storm sewer. Hence, including the effects of dispersion on the transient storm load, the BOD concentration at RP 19 can be estimated at [illegible] mg/l.

A similar procedure is carried out for segments 4,5 and 6, with care being taken to account for the effects of dispersion on the response due to both the SS and CSO loads.

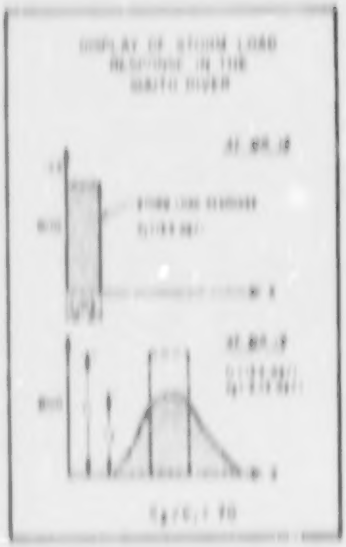


TABLE 5-8
(Continued)

COUPLED SYSTEM (BOD-DO) SAMPLE IMPACT CALCULATION
AVERAGE SUMMER FLOW ANALYSIS
HYPOTHETICAL SOUTH RIVER EXAMPLE

[illegible]

distribution of five day BOD within the segment being analyzed. Similar computations follow for the remaining segments, with care being taken to carry the appropriate concentration and flow values for a given probability level through to the end of the study area. The dissolved oxygen response has been computed in a similar manner. Care must be taken to attenuate the effects of the transient storm sewer and combined sewer overflow loads, so as to account for the effects which dispersion has on them. The procedure for doing this is described in Section 5.2.3 and illustrated in the example calculations as well. These computations are illustrated for one river segment in Table 5-8. The computed dissolved oxygen concentrations for the South River study area are presented in Figure 5-10.

5.2.4.5.1 Dissolved Oxygen Concentration - Drought Flow Periods

Drought flow conditions in the South River study area are found to be 50 cfs for the 7 consecutive day-10 year low flow at the upstream end of the study area. During these periods only dry weather discharges from municipal and industrial sources and tributaries contribute oxygen demanding substances to the receiving waters.

The projected water quality response in the South River is indicated in Figure 5-11. Figure 5-11(a) shows the dissolved oxygen concentration relative to the water quality objectives for the study area at the end of a 20 year planning period. A highly probable water quality problem is indicated in the figure. Dissolved oxygen concentrations are expected to approach 0.0 mg/l in the region between Milepoints 20 and 25 and the entire region between Milepoint 17 and 33 is expected to be below the water quality objective level.

Figure 5-11(b) indicates the impacts due to specific discharges. Municipal wastewater treatment plant No. 2 is the largest single contributor to the problem contributing 65% of the total response at the critical location, Milepoint 23. The industrial discharge and tributary inflow have a minor impact on the projected dissolved oxygen conditions.

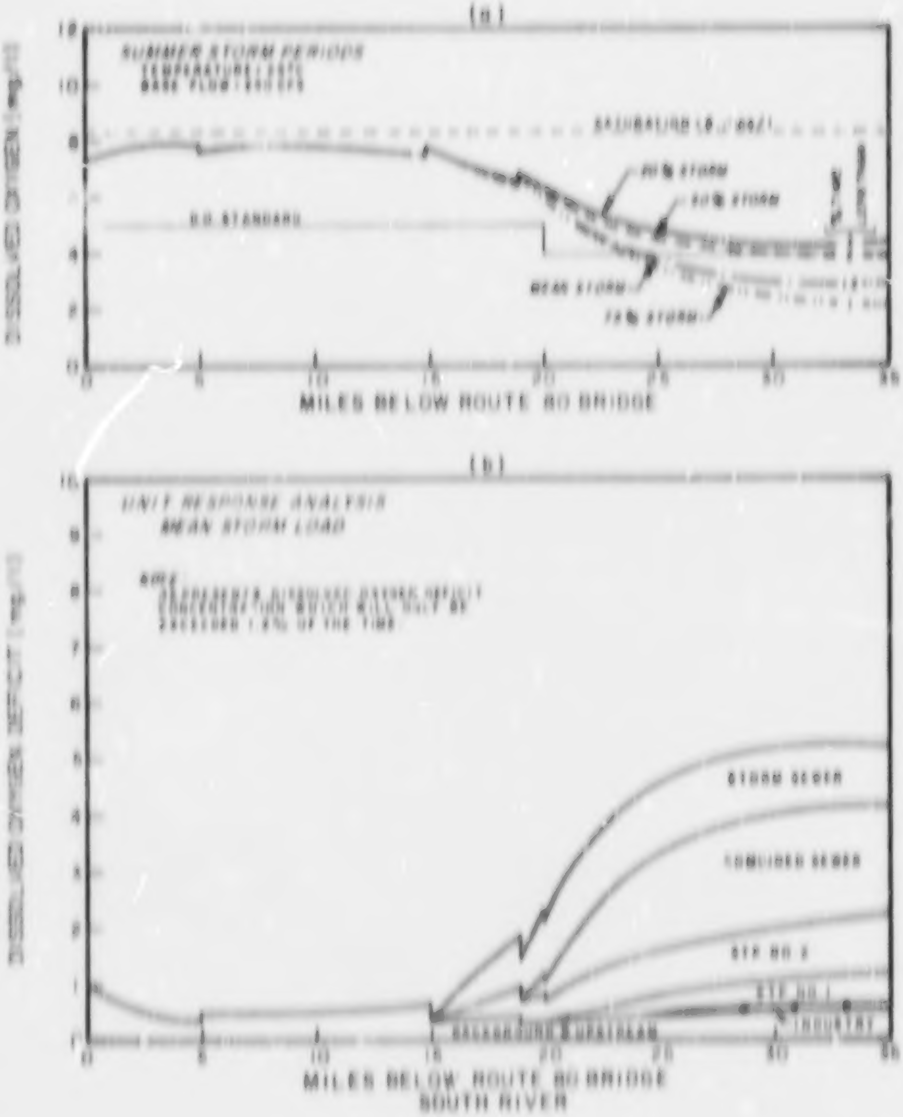


FIGURE 5-10
PROBABILISTIC ANALYSIS OF WET WEATHER DISSOLVED OXYGEN
HYPOTHETICAL SOUTH RIVER

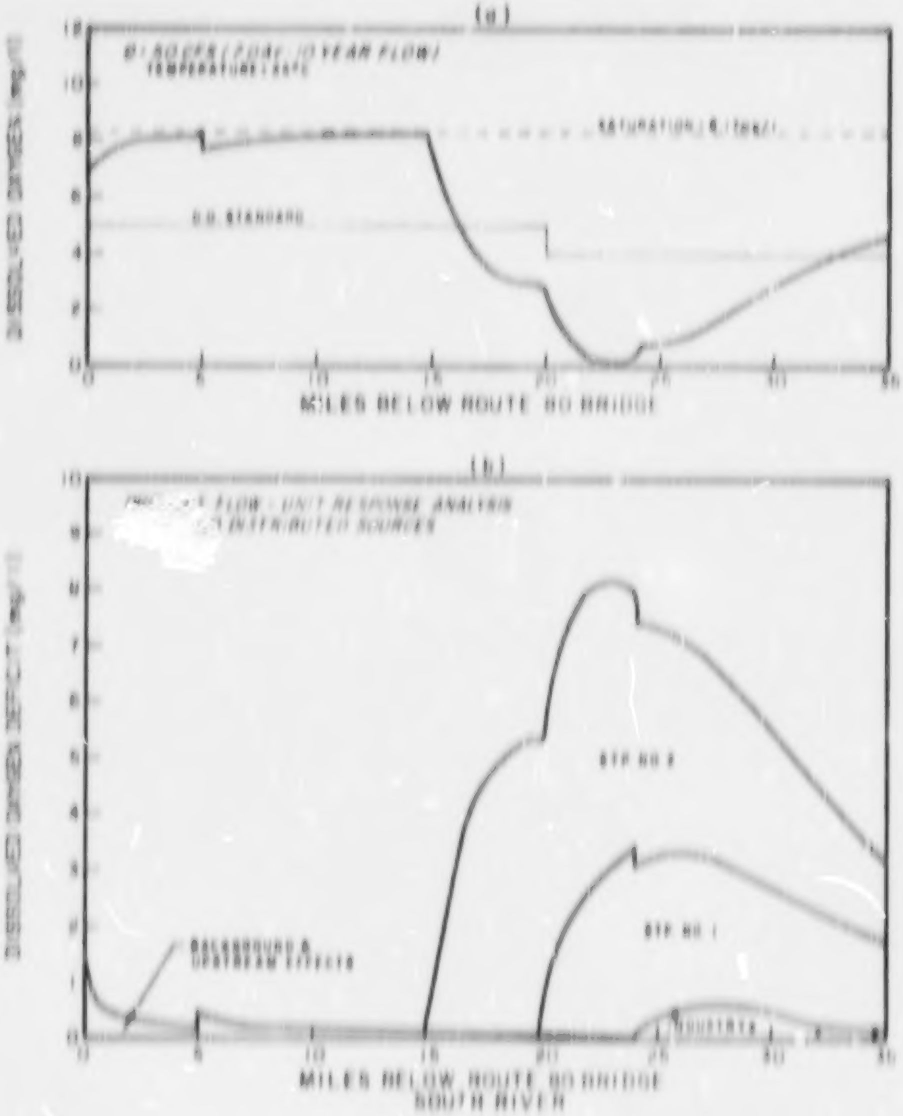


FIGURE 5-11
DRY WEATHER DISSOLVED OXYGEN ANALYSIS
HYPOTHETICAL SOUTH RIVER

5.2.4.5.2 Nutrient Enrichment-Average Summer Conditions

Nutrient enrichment in the South River study area was noted to be a potential water quality problem in Chapter 2. Because nutrient impacts tend to be on a longer time scale, the analysis was made using average summer flows, the long term average summer storm loads (W_O), the point sources, and upstream and background effects. As indicated in Equation 3-21, $W_O = W_R D/\Delta$, and $D/\Delta = 0.0375$ during the summer in the South River area, that is, it rains only 3.75% of the time. The results developed from the equations in Table 2-17 are presented in Figures 5-12(a) for total nitrogen and 5-12(b) for total phosphorus, where the components of the nutrient response due to various loads within the study area are shown. The predicted peak concentrations of 3.95 mg N/l and 1.40 mg P/l are considerably higher than those required to indicate a probable problem.

Figures 5-12(a) and 5-12(b) show that point source loads are expected to be the largest single source of nutrients to the system at the end of the 20 year planning period. Therefore, nutrient removal at one or both of these plants appears to be a potential solution to the problem, if further analyses of nutrient-phytoplankton dynamics (using methods described in Appendix A) demonstrate a need for nutrient reductions. Such an analysis would indicate the nutrient which should be removed as well as the nutrient levels required to maintain an objective phytoplankton level.

5.2.4.5.3 Total Suspended Solids-Summer Storm Periods

Expected total suspended solids concentrations in the South River using the solids decay rate of 0.1/day (pg. 5-8) during the 20%, 50%, mean (68%) and 75% summer storms are shown in Figure 5-13(a). These results indicate a probable problem during summer storm periods. The smaller (i.e., 20%) storms have a smaller impact at Milepoint 15, the location of maximum concentration. The river concentration increases further downstream during these storms, however, due to the continual inflow and background load, with the smaller

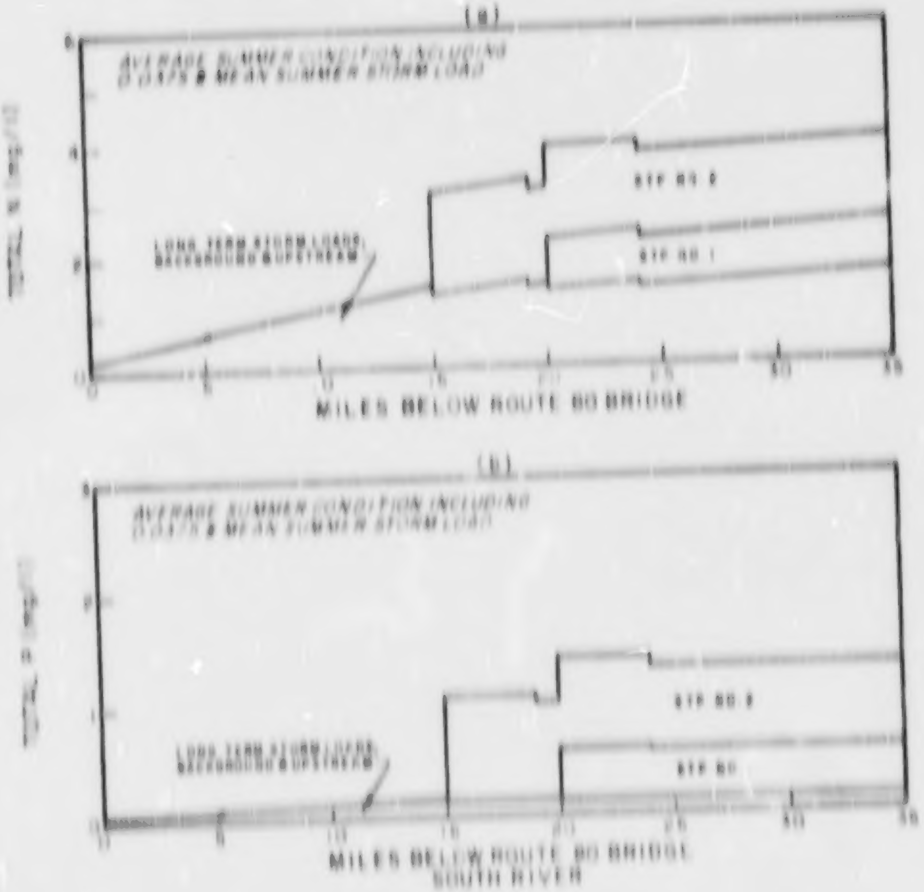


FIGURE 5-12
LONG TERM TOTAL NUTRIENT IMPACTS
HYPOTHETICAL SOUTH RIVER

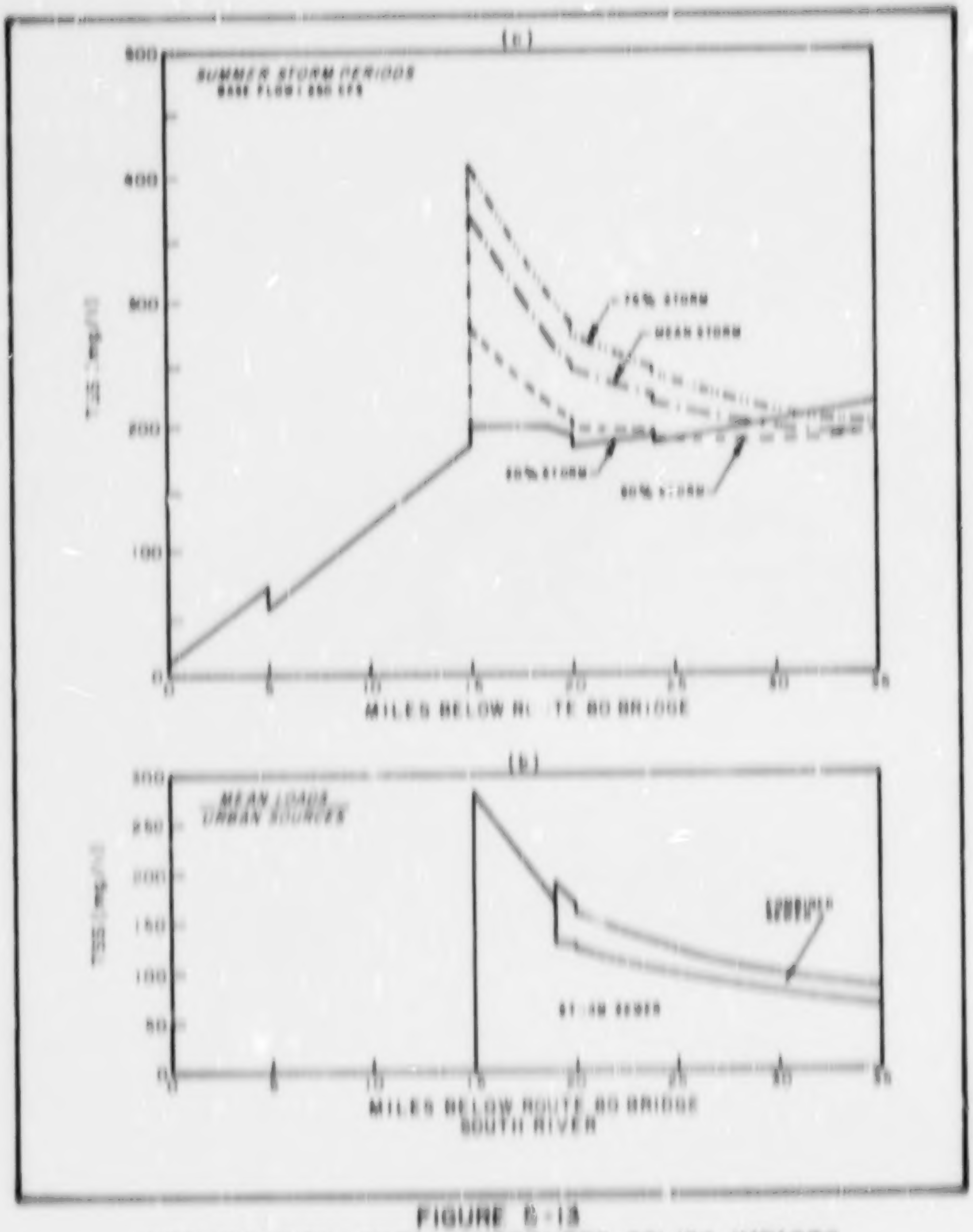


FIGURE 5-13
WET WEATHER TOTAL SUSPENDED SOLIDS IMPACTS
HYPOTHETICAL SOUTH RIVER

diluting flow in the river. It should be noted that the storm impacts are also reduced to compensate for dispersion effects as indicated in Figure 5-4.

The component contributions of the urban sources of total suspended solids during the mean storm are shown in Figure 5-13(b). The municipal treatment plant loads have a negligible impact on the total suspended solids, while the problem is in large part due to storm sewer sources. Another major contributer to the problem is upstream and background sources from agricultural lands which contribute 30 percent of the total observed response at Milepoint 15 during the mean storm. The results indicate a possible need to evaluate control of both non-urban and urban non-point sources of total suspended solids to control the problem.

5.2.4.5.4 Total Coliform Concentration-Summer Storm Periods

Figure 5-14 demonstrates for the coliform die-away rate of 1.26 (pg. 5-8) the 20 year projections for total coliform concentrations in the South River during the 20%, 50%, mean (68%) and 75% storms. Very high concentrations are predicted at Milepoint 10, the location of the combined sewer area load, indicating a highly probable problem. The peak concentration during the mean storm is about 1,200,000 MPN/100 ml.

The mean storm unit response for total coliform organisms is shown in Figure 5-15. The combined sewer systems in sewer District No. 1 contribute heavily to the problem followed by the separate sewer areas. Note that the logarithmic scale used in Figures 5-14 and 5-15 make comparisons of different storm responses difficult, with small vertical differences towards the top of the figures representing large differences in total coliform concentrations, while larger vertical differences towards the bottom of the figures represent small actual differences in total coliform concentrations.

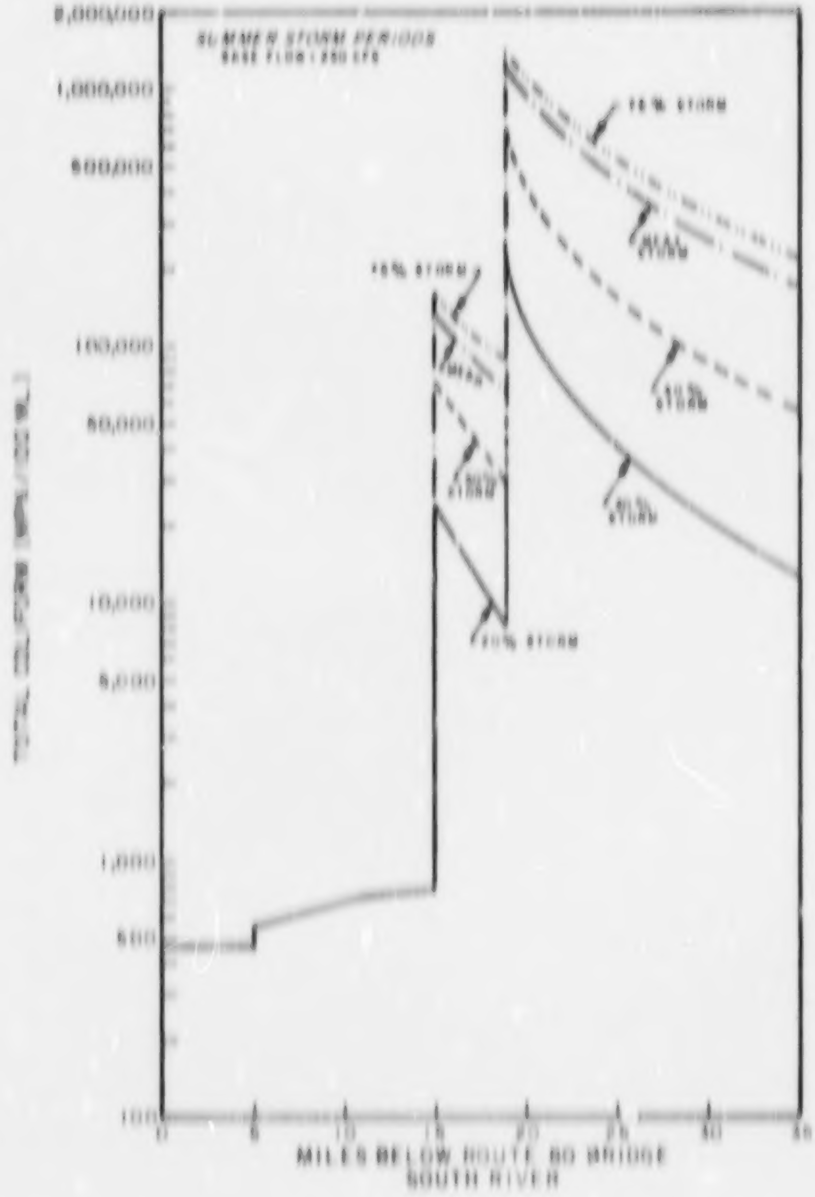


FIGURE 5-14
WET WEATHER TOTAL COLIFORM CONCENTRATIONS
HYPOTHETICAL SOUTH RIVER

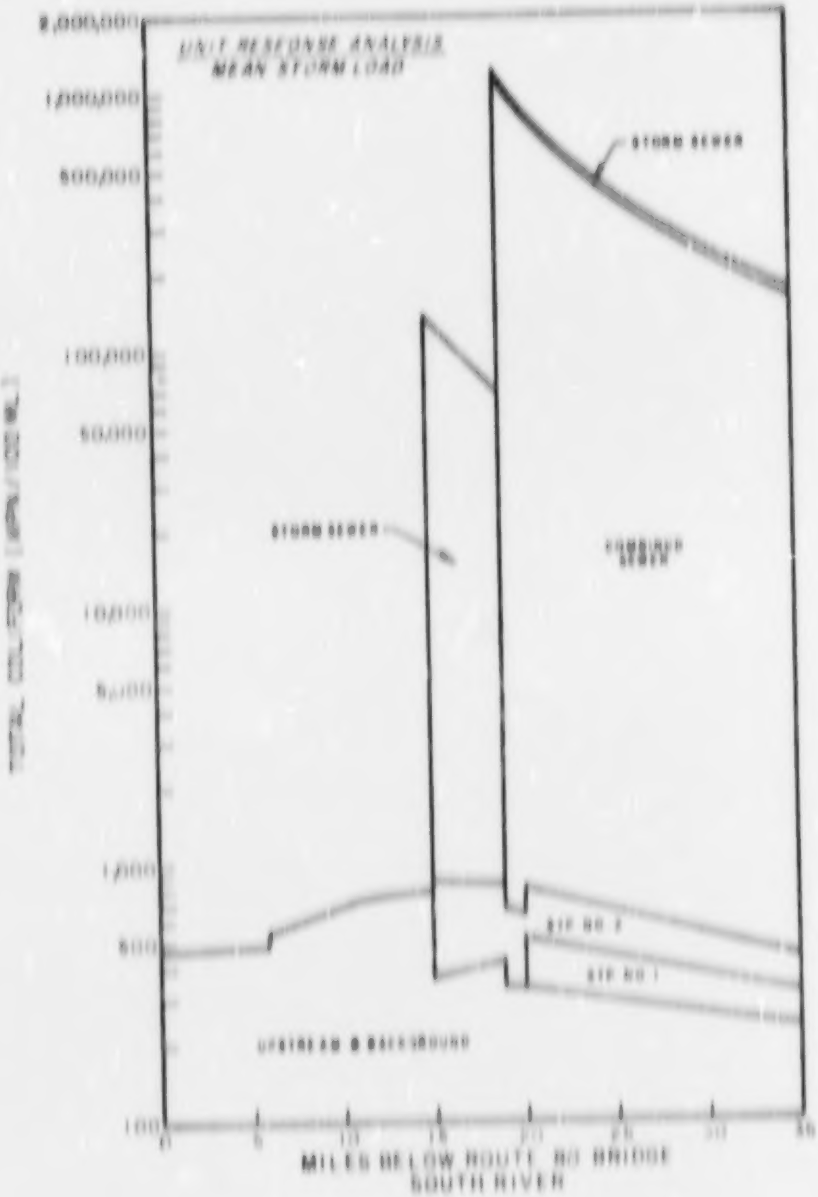


FIGURE 5-15
UNIT RESPONSE TO MEAN TOTAL COLIFORM STORM LOADS
HYPOTHETICAL SOUTH RIVER

5.3 Estuaries

Estuaries are those water bodies in which a significant hydrodynamic transport mechanism is mixing caused by astronomical tides and other similar mixing mechanisms. Estuaries normally consist of two sections which are characterized by the relative magnitude of advective flow to tidal mixing or dispersion. In purely estuarine systems the downstream portion is normally dominated by tidal mixing and freshwater advective flow is less important in transporting physical and chemical constituents. The upper reaches of the estuary are usually influenced by tidal action to a lesser degree because of the damping effect of bottom drag within the estuary. This portion of the estuary is referred to as a tidal river and is characterized by a significant advective transport component.

The analysis of water quality in one dimensional estuaries is somewhat more complicated than in streams principally because of tidal mixing. Materials that are discharged at one point in the system affect water quality in both the upstream and downstream direction because of tidal reversals. The classical method of incorporating this mixing transport in estuaries, and one which finds wide use in engineering practice today, is through the use of dispersion coefficients, normally designated by E. In practice the dispersion coefficient is an estimator of the net rate at which mass is transported from regions of high concentrations to regions of low concentrations. The effect of dispersion is to spread materials discharged to the estuary in the longitudinal direction both upstream and downstream. Due to this phenomenon, a segmented model of an estuary requires simultaneous solution for all segments. The simplified stream analysis, in which upstream concentrations are independent of downstream effects, is not applicable.

Estuaries also differ from streams in the time scale of their response to continuous and intermittent loadings. Generally the response time to loadings is longer in estuaries than in streams. For example, after a continuous source begins discharging into an estuary, concentrations will build up for several days to several weeks before a steady state value is achieved. This is in contrast to advective systems where the concentration buildup at the discharge point is immediate, and equal to the mass balance concentration between the stream and the discharge. Intermittent loads are also acted upon differently in estuaries. Pollutant concentrations due to pulse loads are quickly attenuated because of longitudinal mixing.

This section of the manual considers methods for evaluating water quality responses in estuaries and tidal rivers. The analysis is structured for preliminary assessments similar in design to the preliminary water quality assessment methods for streams presented in Chapter 2. These methods are useful to the 208 planner in the initial development steps of the 208 water quality management plan, and will provide him with a broad overview of water quality problems, the relative magnitude of various waste sources, and the probable impact of the various sources on water quality. From that point the analysis can proceed toward the selection and implementation of appropriate technical procedures to analyse waste sources which are important in the planning area. These technical procedures may be numerical computer models or more refined extensions of the analysis procedures demonstrated in this manual.

In this Chapter, then, all estuarine analyses will be performed on a constant parameter simulator of a real system for which analytic solutions are available. If significant variations in flow, cross-sectional area, dispersion coefficients and kinetic rates, etc. occur within the study area, and if the results of this simplified analysis indicates potential water quality problems, a more sophisticated analysis framework - outside the scope of this manual - is required (Appendix A).

The basic equations for calculating waste concentrations in estuaries and tidal rivers are presented along with guidance for the determination of model coefficients. Example problems are presented to demonstrate the analysis methods for point and non-point sources. Finally Section 5.3.4.1 presents empirical methods for assessing water quality variability. The examples presented in Section 5.3.4.1 are applicable to many local problem cases and should be taken as instructive tools illustrative of techniques which the 208 planner may follow.

5.3.1 Description of Model

For purposes of this chapter, a tidal river is defined as that portion of a water body that is subject to reversals of current direction but does not include estuaries where the effects of freshwater runoff may be small. Thus, tidal rivers that may oscillate in velocity and direction due to causes other than astronomical tides are included in the analysis. An example of the latter case is the flow oscillations in the tributaries of the Great Lakes caused by wind produced seiches. Estuaries are those water bodies that are dominated by tidal dispersion.

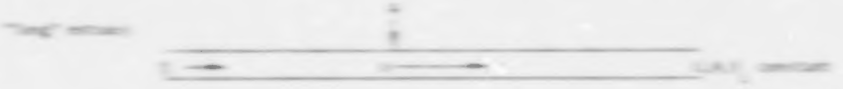
The appropriate general steady state solutions for the tidal rivers and estuaries are presented in Table 5-9 through 5-11 for conservative, reactive and sequentially reactive system variables(7). The reaction coefficient, K, is descriptive of the particular substance under consideration. The velocity, U, is that due to the freshwater discharge. The tidal velocity is not included in the equations, implying that water quality conditions are at mean tide.

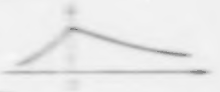
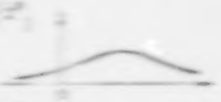
The coefficient, E, is the longitudinal dispersion coefficient. It is most significant in the saline portion of the estuary where a number of factors contribute to the intrusion of the salt into the estuary. The concentration of other substances, which are of concern in water quality analyses of estuaries, is affected in a manner similar to that of the salt. In the tidal, but non-saline sections of the river, the dispersion -- although not as pronounced as in the saline section -- is still a significant factor in the analysis of water quality.

As pointed out previously, the equations for calculating receiving water concentrations (Table 5-9) are applicable to constant parameter estuaries. For gradually varying areas, flows, etc, averaged values are to be input to the equations for preliminary problem assessments.

TABLE 5-9

STEADY STATE EQUATIONS FOR WASTE CONCENTRATIONS IN TIDAL RIVERS AND ESTUARIES DUE TO POINT SOURCE



Type Waste	x ≤ 0	x = 0	x ≥ 0	
Conservative	$c = c_0 e^{Ux/E}$	$c_0 = W/Q$	$c = c_0 = W/Q$	
Reaction (System 1)	$c = c_0 e^{j_1 x}$	$c_0 = W/Q m_1$	$c = c_0 e^{g_1 x}$	
Sequential Reaction (System 2)	$c = \frac{K_{12}}{K_2 - K_1} c_{01}\left(e^{j_1 x} - \frac{m_1}{m_2} e^{j_2 x}\right)$	$c_0 = \frac{K_{12}}{K_2 - K_1} c_{01}\left(1 - \frac{m_1}{m_2}\right)$	$c = \frac{K_{12}}{K_2 - K_1} c_{01}\left(e^{g_1 x} - \frac{m_1}{m_2} e^{g_2 x}\right)$ $x_c = [illegible]$	

DESCRIPTION OF SYMBOLS WITH TYPICAL UNITS

Q = flow (cfs)

U = velocity = $\frac{Q}{A}$ (fps)

A = cross-sectional area (ft^2)

E = dispersion coefficient (mi^2/day)

K_1 = decay rate, system 1 (e.g. BOD) (day^{-1})

K_2 = reaction rate, system 2 (e.g. reaeration rate)

K_{12} = reaction rate between systems 1 & 2, e.g. deoxygenation rate K_d (day^{-1})

W = mass discharge rate (lb/day)

$m_1 = \sqrt{1 + 4K_1E/U^2}$

$j_1 = (U/2E)(1 + m_1)$

$g_1 = (U/2E)(1 - m_1)$

TABLE 5-10

STEADY STATE EQUATIONS FOR WASTE CONCENTRATIONS IN TIDAL RIVERS AND ESTUARIES DUE TO DISTRIBUTED SOURCE

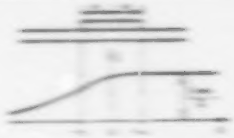
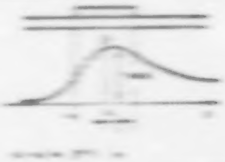
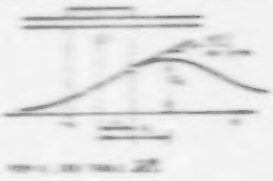
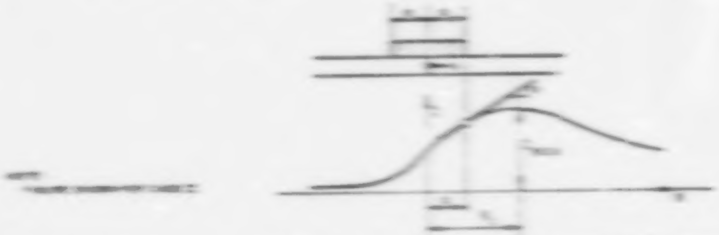
Type of waste	[illegible]	[illegible]	[illegible]	[illegible]
Conservative	[illegible]	[illegible]	[illegible]	
Reactive [illegible]	[illegible]	[illegible]	[illegible]	
Sequentially Reactive [illegible]	[illegible]	[illegible]	[illegible]	

TABLE 5-11

LOCATION OF MAXIMUM CONCENTRATION FOR DISTRIBUTED SEQUENTIALLY REACTING WASTE



[illegible]

[illegible]

Value of s	Location of C_{max}	Implicit Equation for x_1 and Equation for C_{max} when s = 0
I Positive	[illegible]	[illegible]
II Negative	[illegible]	[illegible]
III Zero	[illegible]	[illegible]

5.3.2 Methods of Analysis

5.3.2.1 Conservative Substances

The analysis for conservative substances is identical to that for streams. The maximum concentration at the point source discharge location is simply the mass rate of waste discharge divided by the freshwater flow(Table 5-11):

$$c_0 = \frac{W}{Q} \qquad (5\text{-}5)$$

Note that upstream migration of the waste occurs.

Equation (5-5) may be applied to substances such as total dissolved solids, and other materials which decay at such slow rates that they may be regarded as conservative.

5.3.2.2 Non-conservative Substances

Many substances decay in accordance with a single reaction or at least for practical engineering purposes may be assumed to decay in this fashion. As discussed previously, the reaction is assumed to be first order with a decay coefficient, K.

It should be noted that the following assumptions have been made:

a) steady state

b) constant coefficients exist, i.e., flow, cross-sectional area, reaction kinetics and dispersion characteristics are all constant along the length of the estuary under study.

Since most estuaries vary in cross section along the axis of flow this area must be estimated as the average over which the profile extends at mean tide. For highly reactive substances ($K \geq 2$/day) this distance may be in the order of 10 or 20 miles, while for moderately reacting material ($K \leq 0.5$/day) it may be as much as 50 miles. The difficulty in assigning a realistic average area over such distances is evident from a casual inspection of a geographic map of the coastal areas of the United States. A common physical feature of the topography not taken into account by the above model is the number of tributaries which feed many estuaries and the delta network which characterizes many estuarine mouths. Obviously, a more complete mathematical description of the estuarine structure is required for such situations. In spite of these difficulties, at least, some engineering approximation may be made and the error introduced is invariably on the conservative side.

Table 5-12 presents ranges of values for reaction coefficient in tidal rivers and estuaries for the pertinent substances.

TABLE 5-12

FIRST ORDER RANGE OF VALUES FOR REACTION COEFFICIENTS
TIDAL RIVERS AND ESTUARIES (8)

Substance	K-per day	K-per day[1]
Coliform	2 - 4	1 - 3
BOD_5	0.2 - 0.5	0.2 - 2.0
Nutrients	0.1 - 0.25 or conservative (K = 0)	0.1 - 1.0

[1] From Table 2-19, for rivers.

5.3.2.3 Dissolved Oxygen Analysis

The analysis for dissolved oxygen is conducted in a similar manner. The waste discharge causes a drop in the dissolved oxygen concentration with a subsequent rise further downstream. The tidal river profile is therefore similar to that of the stream. Due to the tidal action, however, the deficit in dissolved oxygen is translated upstream and the associated dispersion flattens the profile. The tidal river profile is therefore projected further upstream and downstream in contrast to the stream profile. The equation of the dissolved oxygen deficit evaluation in estuaries is shown in Table 5-11. As may be seen from these equations the dissolved oxygen deficit profile is determined by the ratio, ϕ, and also the parameter n. The following sections relate to a discussion of these factors.

5.3.2.4 Reaction Coefficients

As in the case of the freshwater stream, the surface transfer coefficient, K_L, is a fundamental expression of reaeration phenomenon particularly appropriate to estuary analysis. It is related to the volumetric reaeration coefficient by the depth.

$$K_a = \frac{K_L}{H} \qquad (5\text{-}6)$$

where: K_L is the surface transfer coefficient (ft/day)(Figure 2-20)
H is the average depth at mean tide (ft.)
K_a is the reaeration coefficient (1/day).

The reaeration coefficient is a function of the velocity and depth of flow. In the tidal river and estuarine case, the pertinent velocity is the average tidal current. The ranges of transfer and reaeration coefficients which may be encountered in estuaries are presented in Table 5-13.

TABLE 5-13

RANGE OF TRANSFER AND REAERATION COEFFICIENTS
ESTIMATED FOR TIDAL RIVERS AND ESTUARIES (8)
(K_L in ft/day, K_a in 1/day)

	Average Tidal Velocity (fps)					
	1		1-2		2	
Mean Tidal Depth (ft)	K_L	K_a	K_L	K_a	K_L	K_a
10	4	0.5	5.5	0.6	7	0.8
10 - 20	3	0.2	4.5	0.3	6	0.4
20 - 30	2.5	0.1	3.5	0.14	5	0.2
30	2	0.06	2.5	0.08	4	0.12

The probable range of K_L is between 3 - 6 feet/day with limits from 2 to a possible 10 feet per day for a shallow estuary with high tidal velocity.

Anticipating the effect of treatment on the oxidation in the natural estuarine environment, the range of the deoxygenation or deaeration coefficient, K_d, may be from 0.2 - 0.5 with a probable average in the order of 0.3, (See Table 5-12). This range assumes that the estuary is no shallower than about 5 feet.

The assimilation ratio, r, may readily be tabulated from the above data and is summarized in Table 5-14 for different conditions.

TABLE 5-14

TABULATION OF ASSIMILATION RATIO - r
TIDAL RIVERS AND ESTUARIES (8)

Reaeration Coefficient K_a (1/day)		r		
K_d =	0.2	0.3	0.4	0.5
0.08	0.4	0.27	0.20	0.16
0.15	0.75	0.50	0.38	0.30
0.30	1.5	1.0	0.75	0.60
0.60	3.0	2.0	1.5	1.2

Tables 5-13 and 5-14 indicate that the deeper main channel estuaries have r values from 0.2 to 0.8, while the shallower tidal tributaries are in the range 0.8 to 3.0. The lower limit of each of these ranges indicates the more restricted tidal bodies of lower velocity, higher temperatures, and effluents from less advanced degrees of treatment, while the upper limit describes the free flowing, higher velocity estuary, and more advanced treatment in more moderate temperature regions of the country.

5.3.2.5 Estuarine Number

In addition to the assimilation ratio, r, the estuarine number, $\eta = KE/U^2$, is the additional specification which characterizes water quality in tidal rivers and estuaries. The practical range of the dispersion coefficient, E, is from 1 to 20 (mi^2/day). The upper limit describes the highly-saline, high-tidal-velocity stretches in the vicinity of the estuarine mouth, while the lower limit applies to the upstream, non-saline, low tidal sections of the estuary. If slack water longitudinal profiles of salinity or chlorides are available, an estimate of the dispersion coefficient may be obtained. This is accomplished by plotting the salinity vs. distance on semi-log paper, fitting a straight line to the data and obtaining E, as described in Reference (7). The dispersion coefficient, E, with the advective velocity, U, provides sufficient hydrodynamic definition for each estuary. The advective velocity associated with the freshwater flow is determined by dividing the freshwater flow, Q, by the average cross-sectional area, A. The dispersion coefficient may therefore vary over a wide range due to the number of geophysical and hydrological factors which affect it, not only within the estuary itself, but also by the characteristics of the drainage basin. The advective velocity U, may range from 0.1 - 10 miles per day. The estuarine number, n, developed from this range of advective velocities and a practical range of dispersion coefficients is tabulated in Table 5-15 for a reaction rate of 0.3/day. For wastes with higher reaction rates, the estuary number increases accordingly. Thus, for coliform bacteria with a decay rate of 3/day, the estuary numbers, n, would be ten times the values tabulated below.

TABLE 5-15

RANGE OF ESTUARINE NUMBER, n,
FOR TIDAL RIVERS (8)
$K_1 = 0.3$/day

Tidal Dispersion (sq. mi/day)	Advective velocity - mi/day 0.5	1.0	2.0	4.0	
2	2.4	0.6	0.15	0.04	= n
5	6.0	1.5	0.38	0.10	
10	12.0	3.0	0.75	0.19	
20	24.0	6.0	1.5	0.75	

A summary of the above tabulations with approximate physical descriptions of the types of tidal rivers and estuaries is presented in Table 5-16.

TABLE 5-16

CLASSIFICATION OF TIDAL RIVERS AND ESTUARIES (8)
(K=0.3/DAY)

Description	Assimilation Ratio (r) Average Value	Assimilation Ratio (r) Range	KE (mi^2/day^2) Aver. Value	KE (mi^2/day^2) Range	Estuary Number "η" Aver. Value	Estuary Number "η" Range
Large, deep, main channel in vicinity of mouth	0.3	0.1-0.5	10	5 -20	15	5 - 30
Moderate navigation channel, upstream from mouth saline, large tidal tributaries	0.5	0.2-1.0	3	2 - 5	5	2 - 10
Minimum navigation upstream, smaller saline or nonsaline tidal tributaries	1.0	0.5-2.0	1.5	1 - 2	2	0.5-5
Tidal tributaries, shallow and nonsaline	2.0	1.0-3.0	.5	.2-1	1	0.2-2

5.3.3 Examples of Estuarine Analyses

Examples of impact evaluations of single point source and multiple waste sources on estuaries are presented below. All analyses are carried out using the steady state equations of Table 5-10 for calculating waste concentrations in estuaries with constant geometry, hydrology and kinetics and having continuous pollutant inputs. For study areas having significantly varying geometry, flows or kinetic rates (e.g., reaeration coefficients), appropriate analyses may be conducted to determine the sensitivity of the result to the varying parameters. Thus, if the cross-sectional area varies widely, analyses can be performed for low, medium and high estimates of the constant area for the entire length of the estuary. If sufficiently diverse results occur under the three assumptions, and if the interpretation of the differences in water quality response show the existence of a water quality problem in one case and the lack of a potential problem in the estuary in another case, a more detailed analysis using computerized models is required. On the other hand, if the impacts vary little and the interpretation of the water quality results is consistent, relative confidence in the analysis results and management decisions may be made based on this simplified approach.

Use of the steady state framework will yield accurate results when reasonably continuous waste sources exist. For intermittent inputs (e.g. storm overflows), the calculated concentrations will generally be higher than those that would result from a more rigorous time variable analysis. For short-term inputs (several hours), the steady state analysis may significantly overestimate the estuarine impact, whereas for longer areawide storms of several days duration reasonably accurate impacts are usually predicted. Since the steady state analysis generates conservative results, its use as a preliminary screening device for relative impacts of waste sources is useful. If continuous sources are cited as the dominant cause of deteriorated water quality, the analysis may be considered as a valid input to management decisions. In those cases where problems are attributable to intermittent sources, care must be exercised in using the results. Where predicted estuarine concentrations are several orders of magnitude above desired levels (e.g. coliform bacteria), the implication of the intermittent source as a problem may be made with confidence. In marginal cases, time variable analysis is required - a topic beyond the scope of this manual.

5.3.3.1 Example of an Estuary Analysis with a Single Point Source

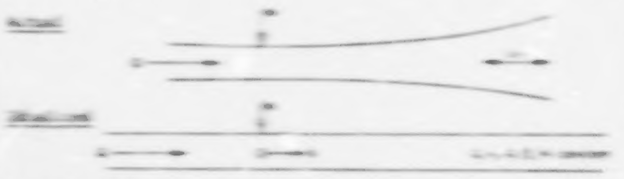
Table 5-17 contains low flow and summer average flow analyses for a continuous point source discharge. A secondary municipal STP is assumed with an effluent flow of 10 cfs and effluent concentrations of total nitrogen (assumed conservative), total coliform and ultimate oxygen demand consistent with data in Table 2-10 (pg. 2-53).

TABLE 3-17

EXAMPLE OF ESTUARY WITH SINGLE POINT SOURCE

Actual

Idealized



Freshwater Flow (Q) [illegible]

Low Flow = [illegible] cfs

[illegible]

Mean Water Depth (H) = [illegible] ft.

Av. Cross Sect. Area (A) = [illegible] sq. ft.

Av. Tidal Velocity [illegible]

Dispersion Coeff. (E) = [illegible]

Point Source Flow [illegible] cfs

[illegible]

Low Flow Analysis

Av. Freshwater Velocity = [illegible]

[illegible]

a) Total Nitrogen Concentrations (Conservative)

[illegible]

[illegible] (Table 3-[illegible])

[illegible]

Upstream of Point Source

[illegible] (Table 3-[illegible])

[illegible]

b) Total Coliform Concentrations (Reactive)

Estuary Number [illegible]

[illegible]

Total Coli. Discharge [illegible]

Max. T. Coli Conc. [illegible] (Table 3-[illegible])

[illegible]

Upstream of PS, [illegible] (Table 3-[illegible])

Downstream of PS, [illegible]

c) Dissolved Oxygen Deficit Concentrations

[illegible]

TABLE 5-17
(Continued)

EXAMPLE OF ESTUARY WITH SINGLE POINT SOURCE

Ultim. Oxygen Demand Discharged = [illegible]

Max. DO Deficit Occurs @ x_{cr} (Table 5-8)

x_{cr} = [illegible]

x_{cr} = [illegible] miles

D_c = [illegible] (Table 5-8)

D_c = [illegible] mg/l

D = [illegible] (Table 5-8)

D = [illegible]

HIGHER RUNOFF FLOW ANALYSIS

Assume no signif. geometric changes, and same dispersion coeff., kinetic coeff., loads.

U = [illegible] mi/day

Using U = [illegible] mi/day, calculations similar to low flow analysis are performed.

a) Total Nitrogen C_0 = [illegible]

C = [illegible]

b) Total Coliform

[illegible]

C_0 = [illegible]

C = [illegible]

C = [illegible]

c) Dissolved Oxygen Deficit

[illegible]

[illegible]

x_{cr} = [illegible] miles

D_c = [illegible]

D_c = [illegible] mg/l

D = [illegible]

D = [illegible]

Comparative plots of resulting concentrations for both flow conditions appear on Figure 5-16.

Freshwater flows of 50 cfs and 300 cfs are used for the low flow and summer average condition and these are assumed constant throughout the estuary. The STP effluent flow of 10 cfs is not included in these values and appropriate sensitivity runs could be made to assess its effect. An average tidal velocity of 0.6 knots is used, a value generally obtainable from annually published NOAA Tidal Current Tables(9). The dispersion coefficient (E) is assumed to be 2 mi^2/day, a value generally representative of the more upstream portion of an estuary. Kinetic rates for the wastes are extracted from Table 5-12.

In the low flow analysis, the maximum total nitrogen concentration is calculated as 4.0 mg/l at the point of discharge. With a freshwater velocity of 0.41 mi/day and an estuary number of 23.8, a maximum total coliform concentration of 20 MPN/100 ml results at the discharge location, indicating minimal impact from this source. Using the average tidal velocity of 0.6 knots (= 1.0 fps) and the average mean water depth of 10 feet, a reaeration coefficient of 0.4/day is generated. The maximum dissolved oxygen deficit of 2.28 mg/l occurs approximately 0.8 miles downstream of the point of discharge. Similar computations are performed for the summer average flow condition. The comparative plots between the two flow conditions, displayed in Figure 5-16, give insight into the behavior of estuaries. The maximum total nitrogen concentrations of 4.0 and 0.67 mg/l are in inverse proportion to the flow, as in stream analyses. On the other hand, the peak total coliform concentrations of 20 and 17.5 MPN/100 ml indicates that the freshwater flow has little effect. The maximum dissolved oxygen deficit of 2.28 mg/l for the 50 cfs flow is reduced to 1.04 mg/l for the flow of 300 cfs showing some reduction to increased flow but not in proportion to the flows. In general, for the more reactive substances the estuary numbers will be higher (n = 23.8, coliform; n = 2.974, BOD; n = 0, total nitrogen) and the impact of flow will be less.

5.3.3.2 Example of Estuary with Multiple Waste Source

Table 5-18 contains analyses for an estuary with a point source representative of a secondary municipal STP (Table 2-10 pg. 2-53) and a

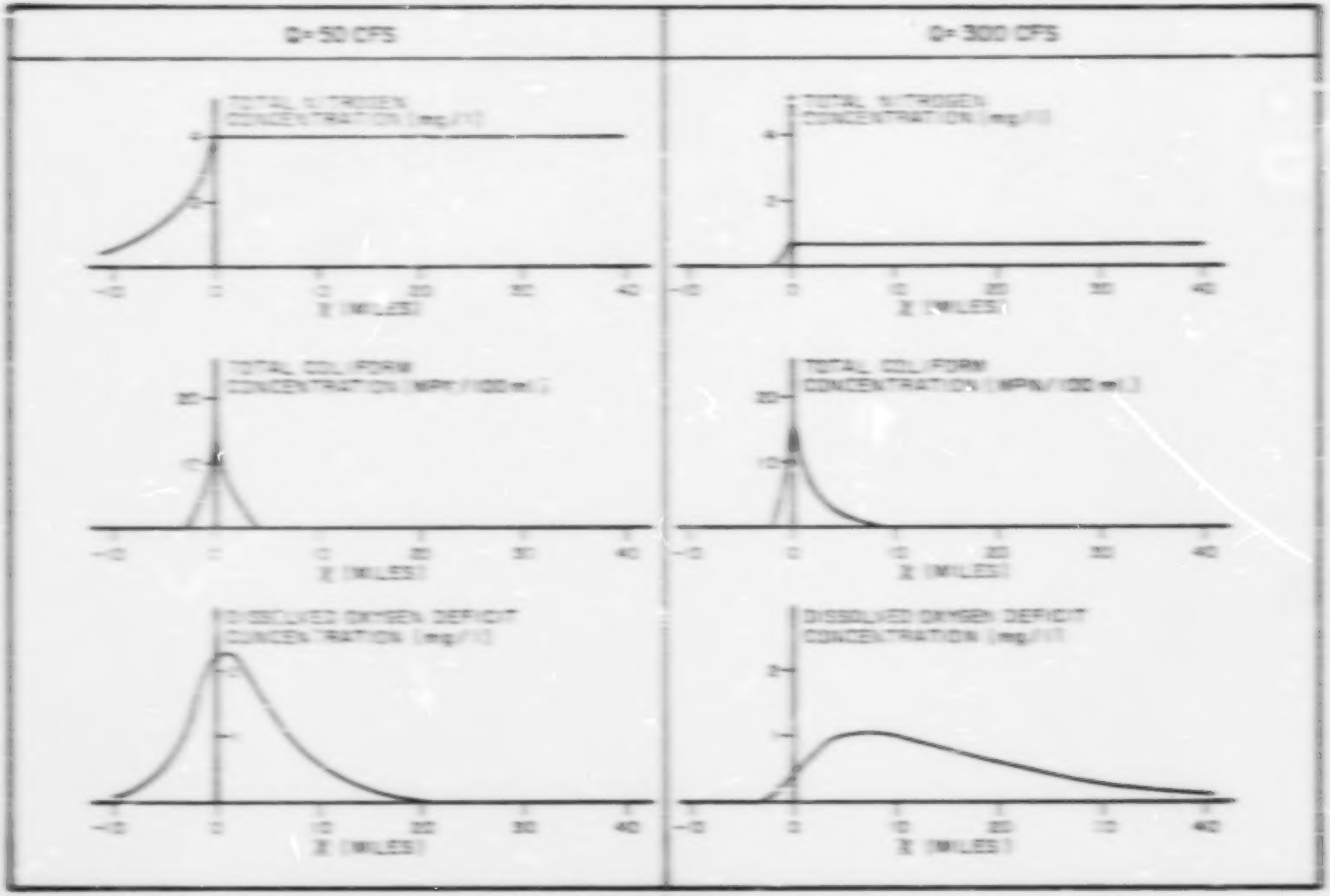
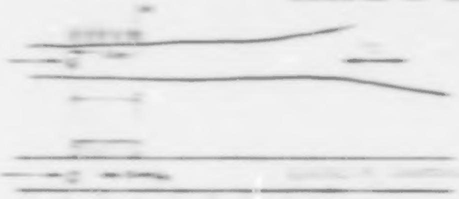


FIGURE 5-16

CONCENTRATION PROFILES FOR ESTUARY WITH SINGLE POINT SOURCE

TABLE 5-28

EXAMPLE OF ESTUARY WITH MULTIPLE WASTE SOURCES



[illegible]

TABLE 5-19

(Continued)

EXAMPLE OF ESTUARY WITH MULTIPLE WASTE SOURCES

DISSOLVED OXYGEN DEFICIT ANALYSIS SUMMER AVERAGE CONDITION

$Q = 220$ cfs, $U = 2.884$ mi/day, $E = 2$ mi^2/day, $K_1 = K_2 = 0.42$/day

$K_1 = K_2 =$ [illegible]

$m_1 = 0.534$, $n_1 = 1.710$, $g_1 = 0.677$/mi, $j_1 = 0.2840$/mi

$m_2 =$ [illegible], $n_2 = 2.071$, $g_2 = 0.734$/mi, $j_2 = -0.234$/mi

From Table 5-11, DO DEF are calculated as follows:

Point Source

$D =$ [illegible]

$D =$ [illegible]

$\bar{x}_c =$ [illegible] $= 2.37$ mi

Non-Point Source

$D =$ [illegible]

[illegible]

$D =$ [illegible]

[illegible]

$D =$ [illegible]

[illegible]

Location of max. deficit (Table 5-_)

$x =$ [illegible] $= 0.228$

Since x [illegible] and so satisfies (Table 5-9)

[illegible]

One would $\bar{x}_c = 2.94$ miles.

	PS		NPS		Total		PS		NPS		Total
MP	x	Conc.	x	Conc.	Conc.	MP	x	Conc.	x	Conc.	Conc.
40	-8	0.02	-6	0.05	0.07	40.65	2.27	1.89*	4.27	0.00	7.88
38	-6	0.08	-2	0.15	0.23	40	3	1.84	5	0.07	1.91
36	-4	0.23	-2	0.47	0.64	40	4	1.86	6	0.80	2.66
35	-7	0.40	-2	0.84	1.03	36	6	1.67	8	0.64	2.26
34	-2	0.73	0	0.73	1.46	34	8	1.29	10	0.50	1.79
33	-1	1.09	1	0.85	2.34	37	10	0.47	17	0.27	0.84
31.34	0.66	1.65	2.66	0.89*	2.74	32	20	0.22	22	0.01	0.22
31	1	1.67	3	0.95	2.62	27	25	0.14	27	0.00	0.15
29	2	1.87	4	0.82	2.69*						

*Max. Conc.

Dissolved Oxygen Deficit - Low Flow

$Q = 15$ cfs, $U = 1.184$ mi/day

$m_1 = 23.22$, $n_1 = 0.681$, $g_1 = 0.2844$/mi, $j_1 = -0.2248$/mi

$m_2 = 23.71$, $n_2 = 33.922$, $g_2 = 0.4901$/mi, $j_2 = 0.4082$/mi

Point Source: $x_c = 1.284$ miles, $D_c = 2.54$ mg/l

Non-point Source: None

distributed intermittent source with characteristics similar to a separate sewer system (Table 2-11, pg. 2-58). Total coliform concentrations are calculated for a summer storm condition typical of a major storm system with a duration of several days. Dissolved oxygen deficits are calculated for summer average and low flow conditions. Estimates of the non-point flows are consonant with the municipal area served and detailed calculation of these values would be performed using methods in Chapter 3.

Using the equations in Table 5-11 for both point and non-point sources, tabular solutions for given estuarine milepoints are set up. The point source solutions are generated for the coordinate system x_p, with origin at Milepoint 52, and the non-point concentrations use an x' - abscissa with origin at Milepoint 51. Following the detailed equations and tabular solutions for both total coliform and dissolved oxygen deficit, plots of the concentration profiles are presented for the combined impact of both sources and the effect of the point source alone in Figure 5-17.

The profiles for total coliform indicate that the separate sewer system is causing over 5,000 MPN/100 ml in the estuary from Milepoint 50 to Milepoint 56 whereas the peak concentration due to the STP is approximately 130 MPN/100 ml. The results for the intermittent separate sewer discharge are reasonably accurate since the bacteria are highly reactive and only require one to several days to approach the equilibrium (steady state) concentration. Thus, it could be concluded that the sewer system is a major source of bacterial contamination and further efforts should be devoted to quantifying its impact on a statistical basis.

The peak dissolved oxygen deficit occurs between Milepoint 49 and Milepoint 50 for the summer average condition. The STP contributes 2.0 mg/l and the separate sewer 0.9 mg/l to the total deficit of 2.9 mg/l. The deficit of 0.9 mg/l from the intermittent separate sewer discharges may be a significant overestimation since the more slowly reactive BOD may require several days to several weeks to attain a steady state concentration. In the low flow analysis without separate sewer discharges, the STP causes a peak deficit of 3.6 mg/l. If one assumes an estuarine chloride concentration of 7500 mg/l (39% seawater) and a water temperature

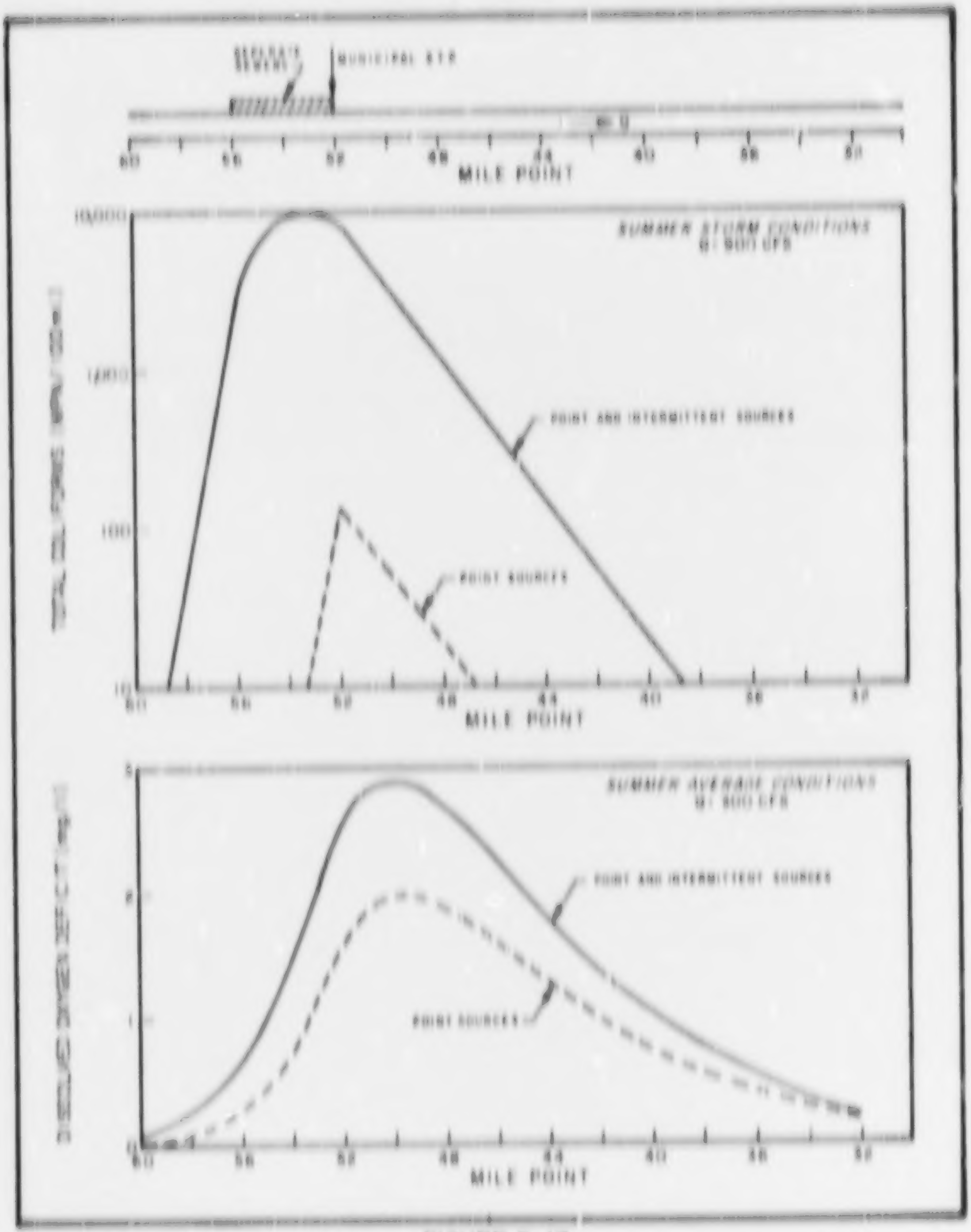


FIGURE 5-17
CONCENTRATION PROFILES-ESTUARY WITH MULTIPLE SOURCES

of 25°C, the dissolved oxygen saturation concentration is 7.7 mg/l (Figure 2-19(b)). Therefore, minimum dissolved oxygen concentrations of 4.6 mg/l and 5.1 mg/l occur in the estuary for summer average and low flow conditions respectively. Depending on the water use and classification, water quality standards may or may not be contravened by these results. In any case, the dominant cause of the deficit is the continuous STP discharge and solution of any dissolved oxygen problem would emphasize alternatives involving the STP.

5.3.4 Methods For Estimating Water Quality Variability in Estuaries

The steady state water quality analysis for estuaries described in the previous sections is appropriate for estimating receiving water responses for annual average loads, or as shown in Section 5.3.3, for water quality analyses of average conditions during critical average or high flow (storm) periods. Another method of evaluating variability in receiving water response is briefly presented in this section.

In cases where the steady state response can be developed using the equations in Table 5-11 or a numerical water quality model, it is often useful to obtain an estimate of the random (at least for purposes of this discussion) variability of that response. Consider the observed and computed water quality profiles shown in Figure 5-18. In this case, the computed response, which adequately represents the mean observed water quality data, is shown to be within the water quality standard. However, the observed variability in dissolved oxygen indicates that frequent measurements are below the standard. An important question is: if mean water quality can be maintained above a standard, as in Figure 5-18, what is the estimated frequency with which the standard will be violated due to random variations about the mean?

The task facing the 208 planner is often one of evaluating the frequency with which water quality objectives will be violated under a wide range of control options, including the 'no action' alternative. Steady state mean responses are generally limited in their interpretation within this context. However, a simple method is presented in this section for

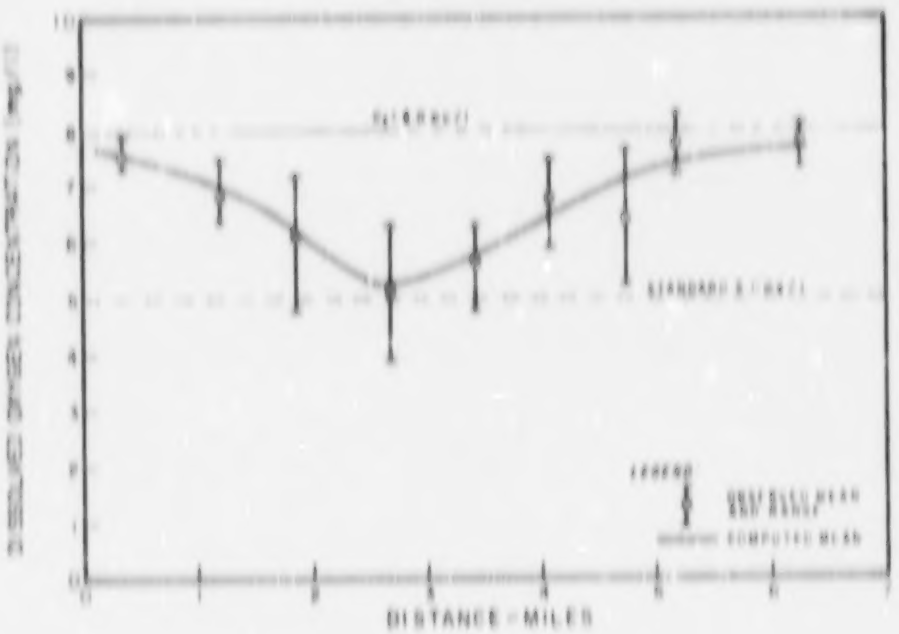


FIGURE 5-18
EXAMPLE SUMMARY OF DISSOLVED OXYGEN DATA
SHOWING VARIABILITY

employing steady state model results in concert with water quality data to estimate the frequency of compliance with water quality objectives.

5.3.1.1 Method of Analysis

In many receiving waters the variability of a water quality indicator increases as the stress on the area increases. The greatest variability around the mean dissolved oxygen response in a stream is expected to occur in the region of the maximum deficit(10). Similar responses are observed in estuaries(11). However, the analytical techniques to evaluate such responses are not straightforward for estuaries.

An empirical approach to analyzing the problem is suggested in Figure 5-19(a) which presents a cross plot of the long term mean and the standard deviation of dissolved oxygen deficit concentrations for a number of sampling stations in South San Francisco Bay. The probability density function at each station must be known and must be the same at all stations. The display indicates a trend in this study area toward increasing variability in deficit concentration in areas of large mean dissolved oxygen deficit concentrations. In this particular case the statistics were shown to be associated with normally distributed deficits at each station.

Figure 5-20 displays a mean computed dissolved oxygen concentration profile for the study area. Also shown in the figure is the estimated lower 90 percentile dissolved oxygen concentration computed in the following manner.

$$\sigma_{\text{def}} = 0.4 + .25\ \overline{\text{Def}} \text{ (from Figure 5-19)}$$

$$\text{Def}_{90} = \text{90 percentile deficit} = \overline{\text{Def}} + 1.28\ (0.4 + .25\ (\overline{\text{Def}})) \qquad (5\text{-}7)$$

where:

$\overline{\text{Def}}$ = mean computed dissolved oxygen deficit concentration = $(C_s - \overline{\text{DO}})$

1.28 = 90% ordinate of the normal cumulative probability curve,

C_s = Dissolved oxygen saturation

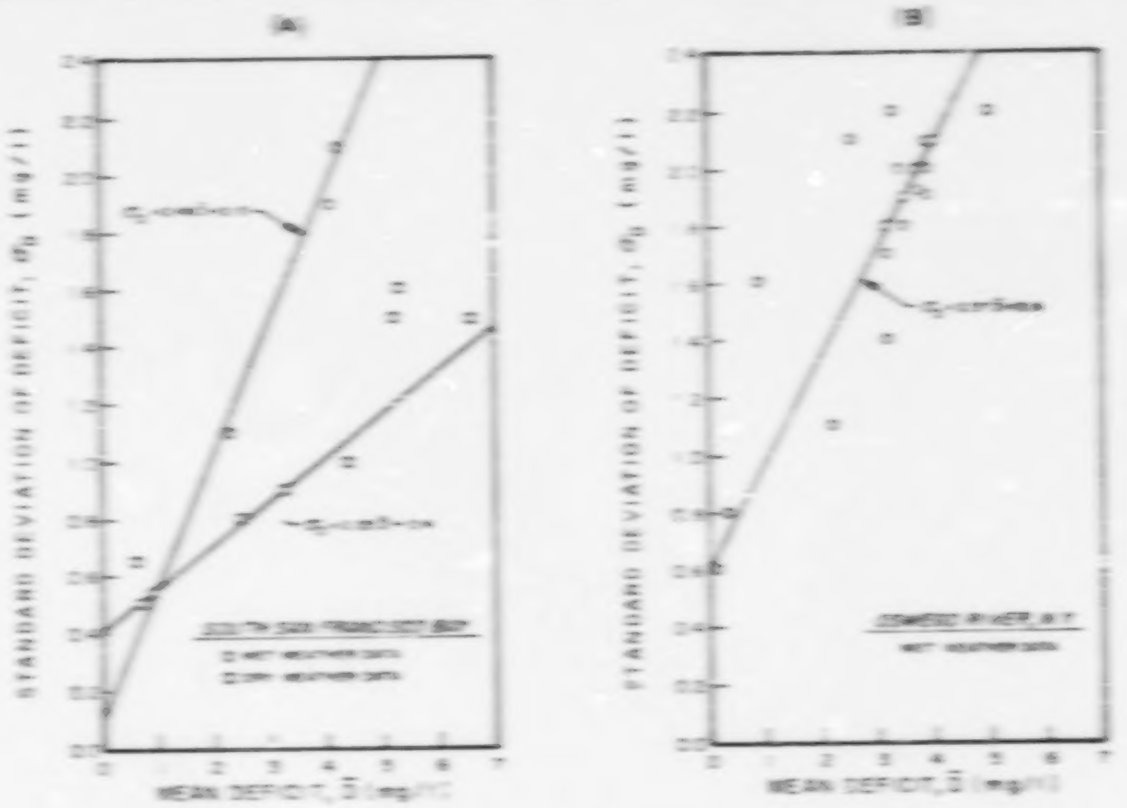


FIGURE 5-19

MEAN VS. STANDARD DEVIATION OF DISSOLVED OXYGEN DEFICIT CONCENTRATION

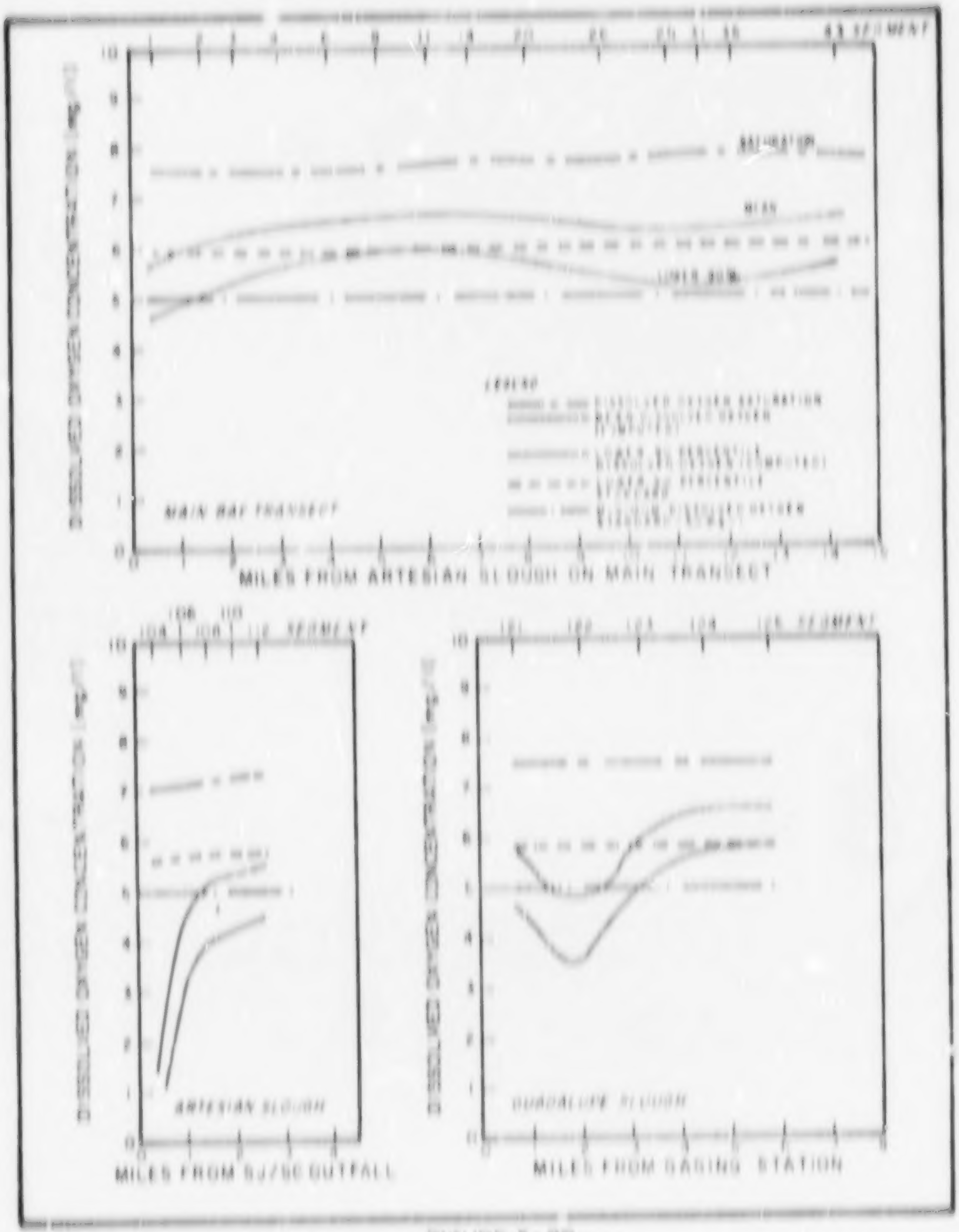


FIGURE 5-20
EXAMPLE OF ESTIMATING VARIABILITY
AROUND STEADY STATE MEAN WATER QUALITY

$\overline{DO}$ = mean computed dissolved oxygen concentration

Def_{90} = 90 percentile deficit concentration

For example, if the mean dissolved oxygen deficit concentration at a location in the South Bay is computed to be 1.2 mg/l and saturation is 7.5 mg/l, the lower 90 percentile dissolved oxygen concentration can be estimated as:

$\overline{Def}$ = 1.2 mg/l

$Def_{90} = 1.2 + 1.27 \times (0.4 + .25(1.2)) = 2.09$ mg/l

$DO_{90} = C_s - Def_{90} = 7.5 - 2.09 = 5.41$ mg/l

where:

DO_{90} = 90 percentile dissolved oxygen concentration.

Conversely, if a relevant planning question is to respond to the frequency with which the 5.0 mg/l standard is expected to be violated in the above example, equation 5-7 can be solved for the ordinate, z, on the normal cumulative probability curve. The formula for this computation is:

$$z = \frac{DO_s - (C_s - \overline{Def})}{0.4 + 0.25\ \overline{Def}}$$

$$z = \frac{5.0 - (7.5 - 1.2)}{.4 + .25(1.2)} = \frac{-1.3}{0.7} = -1.86$$

Cumulative normal distribution tables, found in most statistical texts or (17) can be used to determine that 1.86 corresponds to a 97% event. Therefore, 3% of the dissolved oxygen concentrations at that location might fall below the 5.0 mg/l standard due to random background factors not included in the modeling analysis.

Application of this method need not be limited to dissolved oxygen concentration alone. Relationships similar to those shown in Figure 5-19 can be used to develop background variabilities in specific water quality constituents for purposes of making probabilistic statements using steady state water quality model results. Such methods are particularly useful in estimating the frequency with which standards might be violated in streams or estuaries. The 208 planner is cautioned to pay particular attention to the frequency distribution of the concentrations (i.e., normal, lognormal, gamma) in applying this analysis and also to the sample size used to generate each point in a figure such as Figure 5-10. A sample size greater than 10 observations at each station should be adequate to indicate reliable trends in the data.

5.4 Coastal Areas

The disposal of wastewaters in open water bodies is frequently an attractive wastewater discharge alternative because of the large quantities of available dilution water. The discharge is accomplished using an underwater outfall conveyance line to the disposal site. Good engineering practice usually necessitates a multiport diffuser structure at the terminus of the outfall to facilitate dilution-mixing of the wastewater in the overlying water column. Diffuser design is expensive and requires a comprehensive analysis of many water quality constituents. Caution must be exercised in final design considerations to justify such a structure. Analyses of this type consider such factors as: BOD-dissolved oxygen, nutrients and biostimulation, bioinhibition, sanitary water quality, and aesthetic concerns.

Analysis of water quality in coastal areas and large open water bodies is often viewed as a multi-dimensional problem, the principal features of which are:

1. Plume rise and initial dilution
2. Two dimensional spreading of diluted waste constituents within a mixing zone
3. Advective transport of dilute wastewater mixtures toward shorelines and other vulnerable areas.

The analysis proceeds through separate analysis steps which focus on these three scales of problems (at least until a no effect level of the pertinent water quality constituents is reached). That is, if the analysis indicates that the concentration of pertinent water quality constituents meets objective levels after initial dilution, a conservative estimate of water quality in the mixing zone or at shoreline areas is that it also meets the objective levels.

Section 5.4 presents first approximation analysis techniques and guidelines which are appropriate for analyzing this class of wastewater discharges. The methods can be applied using data collected in the study area in combination with estimated model coefficients which find rather wide application in engineering practice. The methods are also applicable to study areas other than coastal areas. For example open water bodies such as large lakes or large estuaries can be analysed using methods presented here. Guidelines for these analyses are presented with each analysis description. Dispersion coefficients in large lakes can be found in Section 5.5.4.3.

The analysis methods for coastal areas are only for preliminary assessments of water quality impacts. While the methodologies are useful in making level 1 decisions they can and in many cases should be supplemented by more detailed numerical modeling techniques. The 208 planner should exercise engineering judgement in deciding when an analysis indicates the existence of water quality problems which warrant detailed analysis either because of the magnitude of the water quality problem or the costs to implement controls suggested by the preliminary analysis. Guidance in this regard is presented in Section 5.6.

5.4.1 Initial Dilution

Initial dilution is the term applied to the ratio of seawater to wastewater mixed by port discharge of effluent from a diffuser manifold into seawater. Initial dilution takes place during the rise of the effluent plume toward the water surface or to some intermediate trapping level. Momentum of the discharging jet together with the buoyancy associated with density and temperature differences produce shear stresses resulting in boundary turbulence as the plume rises toward the surface. This turbulence facilitates seawater entrainment and dilution of the effluent. The relationships between buoyancy, shear, and dilution are complex and are dependent to a large degree on the ambient density structure in the receiving water. Existence of a moderate salinity gradient or a moderate thermocline may preclude the effluent plume reaching the water surface. This specific case will not be discussed in this manual. However the user is referred to reference (12) for a detailed discussion of nomographic methods for analysing the stratified ocean case. In general the effect of a vertical density gradient is to reduce initial dilution and also the height of rise of the effluent plume. Some guidance in evaluating this case is presented later in this section.

The assumption of a uniform density structure implies vertical uniformity in the receiving water in so far as temperature and salinity are concerned.

In this regard, Rawn, Bowerman, and Brooks (13) using dimensional analysis reevaluated the earlier work of Rawn and Palmer (11), for hydraulic model discharges of submerged jets. The result is an empirical correlation between observed initial dilutions and dimensionless hydraulic parameters which are appropriate to full scale design. Short term dilution varies as a function of distance along the centerline of the effluent plume.

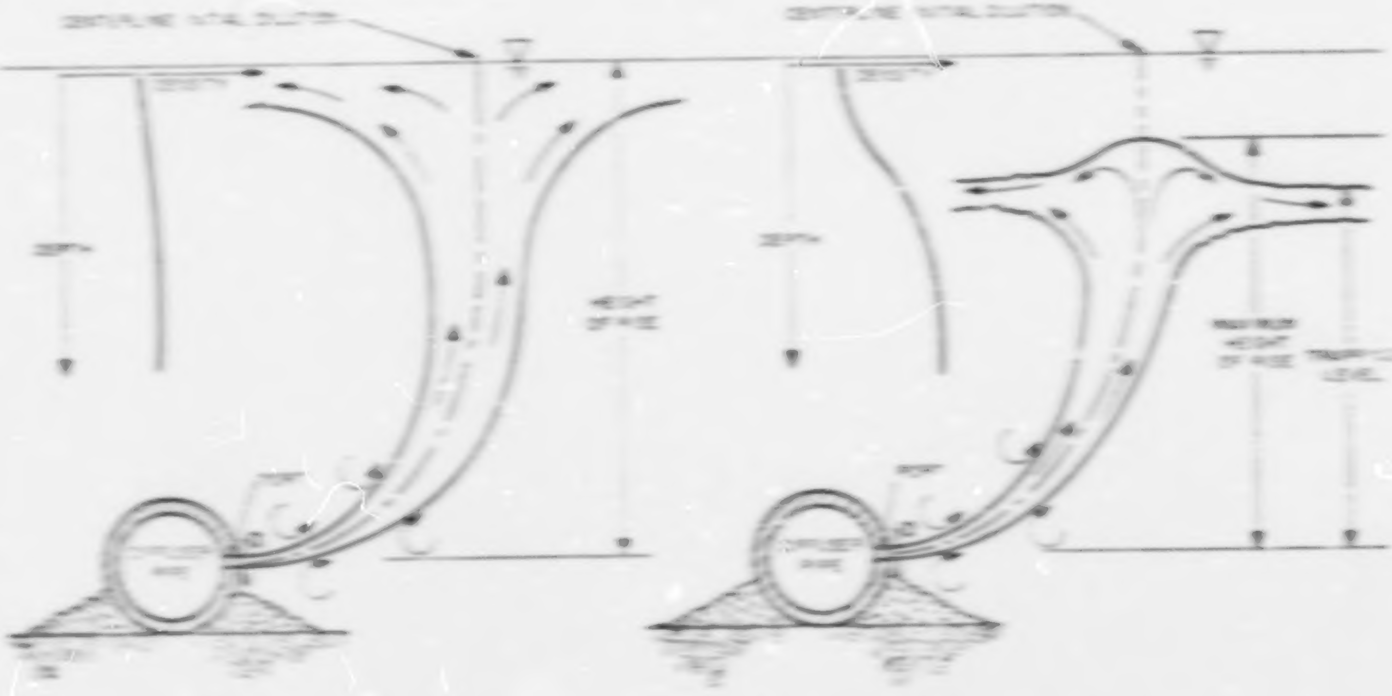
Figure 5-21 schematically shows the effluent plume resulting from a single port discharge as it rises toward the water surface in a stratified and non-stratified environment. Assuming no stratification in the water mass receiving the effluent discharge, S_0, the initial dilution at the center of the surfaced plume, is considered a function of five independent variables: y_0 is the total depth from center of outlet to the surface; D is the initial diameter of jet (approximated by the port diameter); V is the jet velocity; g' is the apparent acceleration due to gravity; and ν is the kinematic viscosity of the sewage.

g' may be expressed as:

$$g' = g\frac{\Delta s}{s} \qquad (5-8)$$

by balancing of forces acting on a buoyed body. In this equation s is the specific gravity of the wastewater, Δs the difference in specific gravity of seawater and wastewater and g the gravitional constant.

It is then possible, to express S_0 as a function of three independent dimensionless parameters:



BUOYANT PLUME RISE IN A MILDLY STRATIFIED WATER COLUMN

BUOYANT PLUME RISE IN A HIGHLY STRATIFIED WATER COLUMN

FIGURE 5-2

BUOYANT PLUME CHARACTERISTICS IN STRATIFIED AND NON-STRATIFIED ENVIRONMENT

$$S_0 = f\left(\frac{Y_0}{D}, F, R\right) \qquad (5-9)$$

where:

The Froude number, $F = \frac{V}{\sqrt{g'D}}$ and the Reynolds number, $R = \frac{VD}{\nu}$.

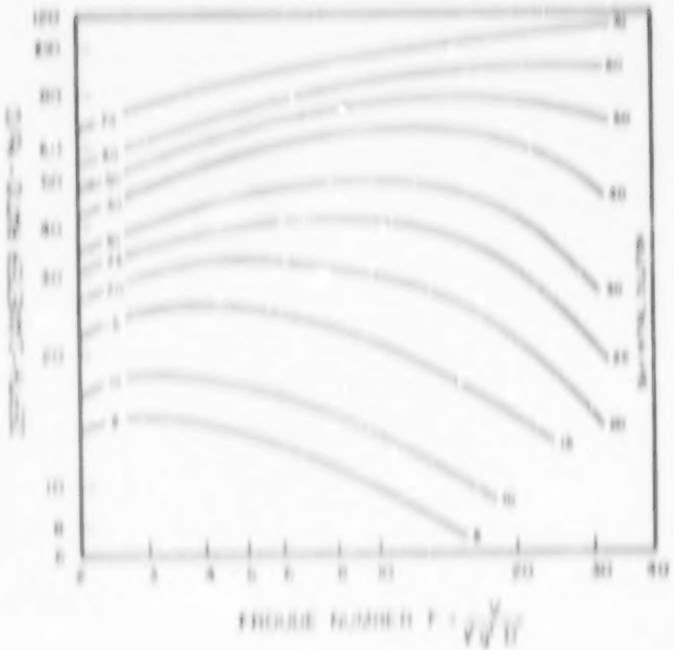
The magnitude of the Froude number reflects the path of jet discharge and plume rise as influenced by gravity and by density differences between seawater and sewage. The Reynolds number is indicative of the effect of inertia and viscosity as a measure of turbulence. Several investigators (13, 15) have presented evidence that, for ranges of turbulent flow, the Reynolds number has little influence on the initial dilution. Apparently, once significant turbulent flow is developed, other hydrodynamic forces are of more consequence to dilution.

Eliminating R as a factor once turbulent flow has developed reduces Equation (5-9) to:

$$S_0 = f\left(\frac{Y_0}{D}, F\right) \qquad (5-10)$$

An illustration of the relationship implied in equation(5-10)is presented graphically with smooth curves in Figure 5-22. This diagram indicates that for a given Froude number, the initial dilution is directly related to the depth of water above the discharging port and inversely related to the diameter of the port. The greater the depth of receiving water and the smaller the port, the greater is the initial dilution. These curves, based on observed initial dilution data, agree reasonably with other theoretical developments, and with a minor modification (empirical) consisting of multiplication of S_0 by 1.15 to account for a zone of flow establishment, are applicable to field conditions. With the above proviso, the curves indicate the minimum initial surface dilution expected from a single round buoyant jet for various conditions of submergence, port diameter, port flow, and density difference.

As an example, assume that the required initial dilution is 50 to 1 (50:1). The question is what water depth is required to achieve this



REFERENCE: [illegible]

FIGURE 5-22
INITIAL DILUTION FOR SUBMERGED HORIZONTAL JET DISCHARGE

objective using a 500 foot diffuser consisting of 40 three inch ports. The design flow is 15 MGD.

An assumption regarding the flow distribution through the ports is required first. A good engineering diffuser design normally distributes the flow uniformly along the outfall. Therefore, the port discharge can be approximated by:

$$Q_p = 15 \text{ MGD} \times 1.55 \frac{\text{cfs}}{\text{MGD}} \times \frac{1}{40} = 0.58 \text{ cfs};$$

The port area is: $A_p = (\frac{3}{12})^2 \frac{\pi}{4} = 0.049 \text{ ft}^2;$

and the port velocity is 11.83 feet per second.

The density of seawater in coastal areas is normally between 1.020 and 1.040 and depends upon nearness to major freshwater discharges from rivers and approaches 1.000 from fresh water areas at the upstream end of tidal rivers. Reference (16) presents methods for computing seawater density from salinity and temperature data. For purposes of the present example, the density of seawater is selected as 1.025, a typical value in many coastal areas. The density of the effluent can normally be taken as 1.00 unless data indicates significant concentrations of total dissolved solids (greater than 1000 ppm).

The Froude number, F, is therefore computed as:

$$F = 11.83 \times \frac{1}{\sqrt{32.2 \times \frac{1.025 - 1.000}{1.000} \times .25}} = 26.4$$

Figure 3-22 yields a required Y/D ratio of 70 to accomplish the required initial dilution. Therefore, the diffuser must be located in 18 feet of water. At low water slack:

$$\frac{Y}{D} = 70 = \frac{Y}{.25}; \; Y = 17.5 \text{ feet}$$

If the outfall discharge rate or effluent quality characteristics are expected to vary between wet and dry weather conditions as might be expected if the treatment plant load is from a combined sewer system, the analysis should be performed for wet weather conditions. In this case the analysis would be repeated for higher flow conditions (i.e., Q = 40 MGD) and the required initial dilution would reflect wet weather effluent quality.

In cases where a non-uniform denisty gradient exists, the foregoing analysis is not supported by experimental data. In those cases the 208 planner can develop an estimate of the range of initial dilutions to be expected in one of two ways, both of which require some experimental data on stable vertical density gradients in the study area. The first method is a very simplified analysis, but one which is generally acceptable for preliminary assessment purposes. Assume a maximum height of rise of the effluent plume by inspecting the vertical density gradients in the study area. The density gradient shown in Figure 5-21(b) is typical of many coastal areas. That is there is a sharp break in the density structure at an intermediate depth. This depth can be used in Figure 5-22 to estimate the maximum initial dilution. For most situations this estimate should not be in error by more than 20 - 30%.

An alternate method for performing more reliable estimates of initial dilution in uniformly stratified coastal areas is presented in Reference (12). This solution to a complex set of experimentally derived relationships yields estimates of the expected height of rise and the expected initial dilution. The reference presents detailed examples of the calculation procedure.

5.4.2 Analysis of Far Field Effects

Ocean disposal of treated effluent necessitates consideration of several factors affecting the final concentrations of contaminants in the nearshore ocean environment. These include physical, chemical, and biological factors, each of which contributes to the total dilution achieved by outfall disposal of wastewaters.

Physical factors include the dilution of effluent constituents with surrounding seawater and dispersion, which spreads the effluent field. In the specific case of bacteria, aftergrowth phenomenon and the natural die-away and predation are additional factors effecting total dilution.

The emphasis in Section 5.4.2 is on analyzing the transport and distribution of coliform bacteria and the consequent impacts on sanitary water quality. The analysis techniques are however appropriate for other water quality indicators such as suspended solids, acute and chronic toxicants, total nutrients and, with some modifications, color.

Bacterial levels are presently the major criteria for evaluating the acceptability of recreational bathing waters and areas of shellfish culture. Therefore, a prime concern in the design of ocean outfall and diffuser systems is the maintenance of coliform objectives at beaches and shellfish beds. Four basic factors are considered in forecasting coliform levels from the discharge of treated wastewater effluent in the marine environment: a) initial concentration in the treated effluent, b) initial plume dilution, c) physical dilution, and d) bacterial aftergrowth and dieoff. Initial concentrations are normally developed from treatment plant effluent records and from land side simulation techniques similar to those presented in Chapter 3. Initial dilution was treated in the previous section of this chapter.

5.4.2.1 Physical Dilution

After the initial dilution of the effluent field is completed, tidal motion and other larger scale phenomenon such as wind and ocean currents spread the field away from the diffuser zone. Longitudinal and vertical mixing are generally assumed to be negligible. Therefore, lateral dispersion is the principal factor responsible for far field dilution known as physical dilution.

Figure 5-23 exhibits an localized surface effluent field as it is translated away from a diffuser device by an ocean current. The diagram indicates the concentration distribution of material in the effluent field as it moves along the longitudinal axis, x, from the diffuser device at current velocity, U. The initial concentration C_0, in a field width, b, is almost uniform in the immediate vicinity of the diffuser structure. However, as the field is translated and is dispersed along the lateral axis, concentration gradients develop. The maximum concentration along the centerline of the effluent field decreases and

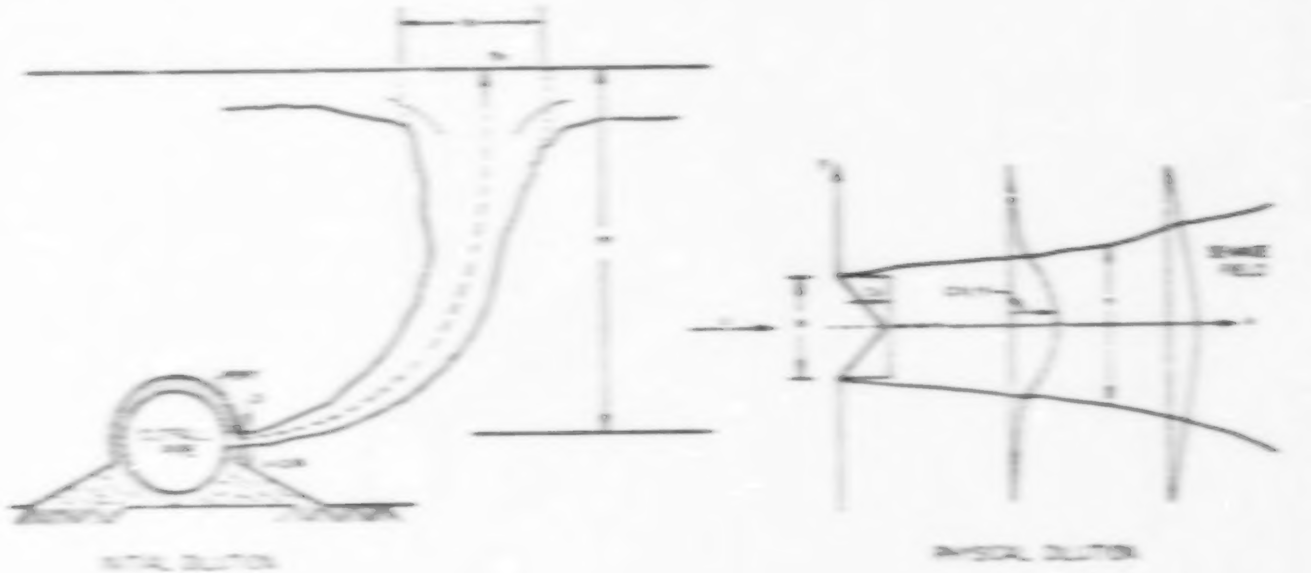


FIGURE 5-23
DIAGRAM OF INITIAL AND PHYSICAL DILUTION

is gradually reduced toward the limits of the effluent field. The concentration of any effluent material is related therefore, to longitudinal distance, x, and the lateral spread, y, of the effluent field.

A mathematical representation of this phenomenon predicts the short-term steady state concentration of an effluent field produced by discharge from a multiport diffuser.

The partial differential equation governing this phenomenon is discussed by Brooks (17). The equation is solved for the case of variable dispersion coefficients. It is assumed that lateral dispersion, expressed by the coefficient E_y, varies with distance along the longitudinal axis of the effluent field as a function of the field width. Based on empirical evidence and theoretical development, oceanic dispersion coefficients have been related to scale by the following expression:

$$E = \varepsilon L^{4/3} \qquad (5\text{-}11)$$

where:

E = the lateral dispersion coefficient

L = the width of the effluent field,

ε = an empirical constant.

A value of $\varepsilon = 0.01$ for cgs units is suitable for surface effluent fields. No information is presently available in the literature for the submerged field case; that is, the case in which the effluent plume remains submerged below the density gradients shown in Figure 5-21(b).

By applying the pertinent boundary conditions, and assuming that the lateral dispersion coefficient varies with scale according to equation (5-11) where L is taken as the projected width of the effluent field normal to the current, the concentration of an effluent constituent at various distances from the outfall diffuser is:

$$C = C_0 \, \mathrm{erf} \left[\frac{3/2}{\left(1 + \frac{8 E_0 x}{U b^2}\right)^3 - 1} \right]^{1/2} \qquad (5\text{-}12)$$

in which:

C = concentration along x-axis of the effluent field direction of current

C_0 = concentration at $x = 0$

x = distance along x-axis of effluent field

U = current velocity along the x-axis

b = initial width of effluent field above the diffuser and normal to the current

E_0 = lateral dispersion coefficient at $x = 0$ as defined by equation (5-11) where $L = b$

erf(z) = error function $\frac{2}{\sqrt{\pi}} \int_0^z e^{-z^2} dz$

Once an outfall and diffuser system has been designed on a preliminary basis from initial dilution considerations, equation(5-12) is normally used to determine the pattern and concentration of the resultant effluent field and physical dilution. The lateral dispersion coefficient is assigned on the basis of diffuser orientation, diffuser length and initial field width. Current velocity information may be obtained from Tide and Current Tables and Tidal Current Charts prepared by the National Oceanographic and Atmospheric Administration. This information can be obtained by writing to: National Ocean Survey, Rockville, Maryland 20852 or a local sales office (normally located at marinas or marine supply sales centers).

5.4.2.2 Biological Factors

Discussion to this point has been limited to those physical factors which affect dilution and dispersion of the effluent. All effluent constituents are subject to physical dilution phenomena. However, certain constituents, notably organics and bacteria are subject to reactions which result in a concentration decay.

Bacterial populations undergo growth and death in a natural environment. To incorporate this phenomenon into equation (5-12), a first order reaction rate, k, is assumed. The resulting equation is:

$$C = C_0 e^{-\frac{kx}{U}} \operatorname{erf}\left[\frac{3/2}{\left(1 + \frac{8E_0 x}{U b^2}\right)^3 - 1}\right]^{1/2} \qquad (5\text{-}13)$$

where t is the reaction time, and may be expressed as x/U.

Currently available information on the behavior of bacteria in the marine environment suggests the possibility of an aftergrowth phenomena after discharge into a receiving water. The aftergrowth is followed by a rapid die-away of the bacteria. Sequential aftergrowth and die-away have been postulated as first-order reactions and are normally included in bacterial analysis using equation 5-13. There are two methods of treating aftergrowth phenomenon in equation (5-13). The first is to apply an aftergrowth factor to the initial concentration, C_0. Thus: $C_i = A\, C_0$, where A is the aftergrowth factor expressed as a multiple of the initial concentration in the effluent field. The magnitude of the aftergrowth is strongly dependent upon water temperature and incident ultraviolet solar radiation. Typically aftergrowth factors range between 1.0 [illegible] 3.0. The lower end of the range is indicative of warm waters in sunny conditions such as might occur in the southern portions of the United States. The higher aftergrowth factors are normal in areas where the sunlight intensity is low or where water clarity is poor.

A second method of estimating aftergrowth is through a modification of equation (5-13) to include both the die-away and aftergrowth processes. The resulting equation is similar to equation (5-13) and reflects a separation of the overall reaction rate, k, into its two components: k_1, a die-away coefficient, and k_2, an aftergrowth coefficient.

$$C = C_0 e^{-k_1 t} e^{k_2 t} \operatorname{erf}\left[\frac{3/2}{\left(1 + \frac{8E_0 x}{U b^2}\right)^3 - 1}\right]^{1/2} \qquad (5\text{-}14)$$

Where k_1 is treated as a constant in time and k_2 is a positive aftergrowth rate in the time interval t = 0 to t = T_A. T_A is defined as the time required to realize the aftergrowth fraction A as defined above. Thus:

$$A = e^{K_2 T_A} \quad T_A = \frac{\ln A}{K_2} \tag{5-15}$$

An aftergrowth factor of 3 in 12 hours is typical of marine systems. Therefore: $K_2 = \frac{\ln A}{T_A} = \frac{24}{12} \times \ln(3) = 2.2$ per day.

Knowledge of the physical and geometric parameters of the diffuser and oceanic systems, along with estimates of the appropriate reaction rates, allows the calculation of the probable concentration of substances at any distance from the point of discharge (for various current velocities and directions) on a short-term basis.

5.4.2.3 Application of Analysis Methods

An example of the methods for evaluating water quality at locations remote from the diffuser are demonstrated in this section. A diffuser with characteristics described in Section 5.4.1 is used. In the example, only sanitary (bacterial) water quality is evaluated. Other parameters can be evaluated in a similar manner. The basic data is:

Required initial dilution (S_0) = 60:1
Length of Diffuser (L) = 500 feet
Discharge Depth = 18 feet
Mean Current Velocity (U) = 50 fpm (0.83 fps)
Oceanic Diffusion (E_0) = $0.01\ L^{4/3}$ (cgs units)
Effluent coliform conc. (C_e) = 10^4 MPN/100 ml
Coliform Die-away rate (K_1) = 1.0 day^{-1}
Coliform Aftergrowth rate (K_2) = 2.2 day^{-1} (12 hours).

The maximum concentration of coliform organisms at a shellfish harvesting location 10,000 feet away from the diffuser is estimated as follows:

$$C_o = C_e/S_0 = \frac{10,000}{60} = 170 \text{ MPN/100 ml}$$

$$E_0 = .01\ (500 \text{ ft} \times 30.5 \text{ cm/ft})^{4/3} = 3782 \frac{\text{cm}^2}{\text{sec}} = 4.1 \frac{\text{ft}^2}{\text{sec}}$$

$$t = 10,000/50 = 200 \text{ Min} = .14 \text{ days}$$

Therefore, aftergrowth is appropriate for the entire spatial interval.

$$C = (167)e^{-1.0(0.14)}e^{2.2(0.14)}\ \mathrm{erf}\left[\frac{3/2}{\left(1 + \frac{8(4.1)(10,000)}{0.83(500)^2}\right)^{1/2} - 1}\right]^{1/2}$$

$$C = 197\ \mathrm{erf}(0.306)$$

The error function is evaluated using standard error function tables (16) to be 0.893, and:

$$C = 176\ \mathrm{MPN}/100\ \mathrm{ml}$$

Therefore, the coliform concentration within the shellfish area is expected to be 176 MPN/100 ml under the assumed conditions. Conditions at other current velocities can be similarly computed and compared to water quality standards for sanitary water quality for shellfishing within the study area. The computed concentration, 176 MPN/100 ml at mean current velocities normally indicates a high probability of a problem in a shellfishing area. Local standards should be consulted before evaluating the problem further.

5.5 Lakes and Impoundments

Information presented in this section is taken in large part from reference (81). Lakes and impoundments are characterized by physical features which result in a special class of water quality problems. The relatively long detention times in these systems permit relatively slow reaction processes to proceed to completion; response times to changes in loadings are longer than for river or estuary systems; and transport characteristics in three-dimensions are frequently required to adequately analyse the system. The procedures and methods presented in this section are designed to permit the 208 planner to analyse lake systems in a preliminary assessment framework. The methods focus on major problems and yield fundamental relationships between loads and water quality which must be interpreted prudently. The planner is cautioned to exercise critical judgement in using Section 5.5, and utilize qualified persons and consultants in analysing problem frameworks which are beyond the scope of these analyses.

Lake systems have historically been analysed in numerous frameworks; from simple empirical analysis methods to sophisticated numerical models of transport and kinetic reactions. This section of the manual deals with lake water quality in terms of the simpler methods and relatively straight forward numerical methods which can be performed with an electronic calculator. Stratification in lakes is described in terms of a dimensionless parameter so that first cut assessments of the vertical dimension of water quality problems can be determined. Empirical methods for assessing nutrient loadings are then reviewed to place eutrophication problems in perspective. Methods suggested by Vollenweider and Dillon (20,21) are employed for this purpose. Finally, closed-form solutions to equations for analysing a wide spectrum of special water quality problem types are presented and demonstrated. Where appropriate, assumptions and limitations are clearly spelled out.

5.5.1 Stratification in Lakes and Impoundments

A method for classifying lakes as deep stratified systems, weakly stratified, or vertically mixed is fundamental to defining the vertical dimension of water quality problems in lakes. The classification system is based on the ratio of the inflow volume to the storage volume in the impoundment. Three classes are defined as follows:

a. Deep stratified lake (low flow to volume ratio). Reservoirs in this class are large and have detention times greater than one year. They are characterized by periods of strong vertical stratification.

b. Weakly stratified lakes (medium flow to volume ratio). Large lakes with detention times in the order of four months to a year are normally in this class.

c. Vertically mixed (large flow to volume ratio). This class generally includes run-of-the-river impoundments with detention times less than four months. Vertical temperature gradients are not present; however, longitudinal temperature variations may exist.

Determination of the impoundment classification is made by computing its densimetric Froude number (F_D). This number is the ratio of the inertial force of the horizontal flow to the gravitational forces within the impoundment. Consequently, it is a measure of the ability of the horizontal flow to alter the internal density structure of the reservoir from its static equilibrium condition. The densimetric Froude number is given by:

$$F_D = \frac{LQ}{DV} \sqrt{\frac{\rho}{g\epsilon}} \qquad (5\text{-}16)$$

where:

F_D = densimetric Froude number

L = reservoir length (ft)

D = mean reservoir depth (ft)

Q = flow through the reservoir (cfs)

V = reservoir volume (ft^3)

g = gravitational constant (ft/sec^2)

ϵ = average normalized vertical density gradient (5.25×10^{-7} $lbs/ft^3 \cdot ft$)

ρ = reference density.

Substituting values for the constants g, ρ, and ε, the equation simplifies to:

$$F_D = 320 \frac{L}{D} \frac{Q}{V} \qquad (5\text{-}17)$$

The use of this equation is demonstrated in Table 5-13. In a deep lake where the isotherm is horizontal, the inertia of the longitudinal flow will be insufficient to disturb the overall gravitational (or density) static equilibrium state of the lake. Local disturbances may occur at points near the tributary inflow and the lake outlet. Thus, the F_D for such an impoundment is small. For the vertically mixed reservoir, the inertia of the inflow is sufficient to completely upset the density structure, leaving the impoundment non-stratified. F_D for reservoirs of this class is large. Between these two extremes lies the "gray area" which includes the weakly-stratified reservoirs. Here the longitudinal inflow has enough inertia to disrupt the gravitational static equilibrium configuration but is not sufficient to completely mix the reservoir.

Theoretical and experimental work in stratified flow indicates that flow separation or stratification occurs in systems having F_D values in the order of $1/\pi$ or 0.32. For F_D values less than 0.32, the water flow will be longitudinal or stratified, while for F_D values greater than 0.32, the water column is more mixed in the vertical direction. A general rule to follow is:

F_D values $\gg 0.32$ - completely mixed lake

F_D values $\ll 0.32$ - deep, stratified lake

F_D values $\cong 0.32$ - weakly stratified lake.

Table 5-19 presents the Froude number for a selected group of reservoirs and demonstrates the classification system presented above. The value of the specific Froude number which would distinguish the transition from one classification to another has not yet been clearly determined.

5.5.2 Eutrophication Assessment Methods

Assessments of the eutrophication potential in an impoundment is of concern because of the long detention times of these systems. Eutrophication is very complex and not easily adapted to simplified analysis techniques. Various approaches have been used to empirically evaluate the conditions in impoundments. The most widely used one is discussed here. Several other techniques are also available. The applicability of these techniques to a site specific study area must be determined on an individual impoundment basis. The manual user selecting such a method should become familiar with the various assumptions involved in its development and determine if these assumptions are valid for the impoundment under study.

TABLE 3-19

CALCULATION OF FROUDE NUMBER F_D FOR LAKE CLASSIFICATION

Reservoir	Length (feet)	Average Depth (feet)	Discharge to Volume Ratio (sec^{-1})	Froude Number F_D	Class
Lake Roosevelt (Wash)	2.0×10^5	70	5.0×10^{-7}	0.46	Weakly Stratified
Priest Rapids (Wash)	2.9×10^5	28	4.0×10^{-4}	1.4	Vertically Mixed
Wells (Wash)	4.8×10^5	35	6.7×10^{-4}	3.9	Vertically Mixed
Detroit (Ore)	1.5×10^5	150	3.2×10^{-6}	0.005	Deep
Hungry Horse (Mont)	4.7×10^5	70	2.2×10^{-6}	0.0026	Deep
Lake [illegible] (Tx)	36×10^3	7	5.3×10^{-7}	0.32	Weakly Stratified
Lake Livingston (Tx)	2.8×10^5	6.5	1.8×10^{-7}	0.32	Weakly Stratified

One of the earliest efforts to relate external nutrient loadings to eutrophication was accomplished by Vollenweider (20). Vollenweider plotted the phosphorus loading to a number of lakes as a function of the mean lake depth to provide a basis for classifying the eutrophic status of the water body. Dillon (21) has expanded this approach to include the consideration of the effect of hydraulic detention time on nutrient loadings and nutrient retention. Consideration of the hydraulic detention time provides an improvement over the Vollenweider approach. This improvement is realized because two impoundments with the same mean depth may have considerably different detention times. For example, one might be a run-of-the-river type impoundment while the other is a storage reservoir. The eutrophic potential of the run-of-the-river impoundment will be less due to the higher washout rate of nutrients.

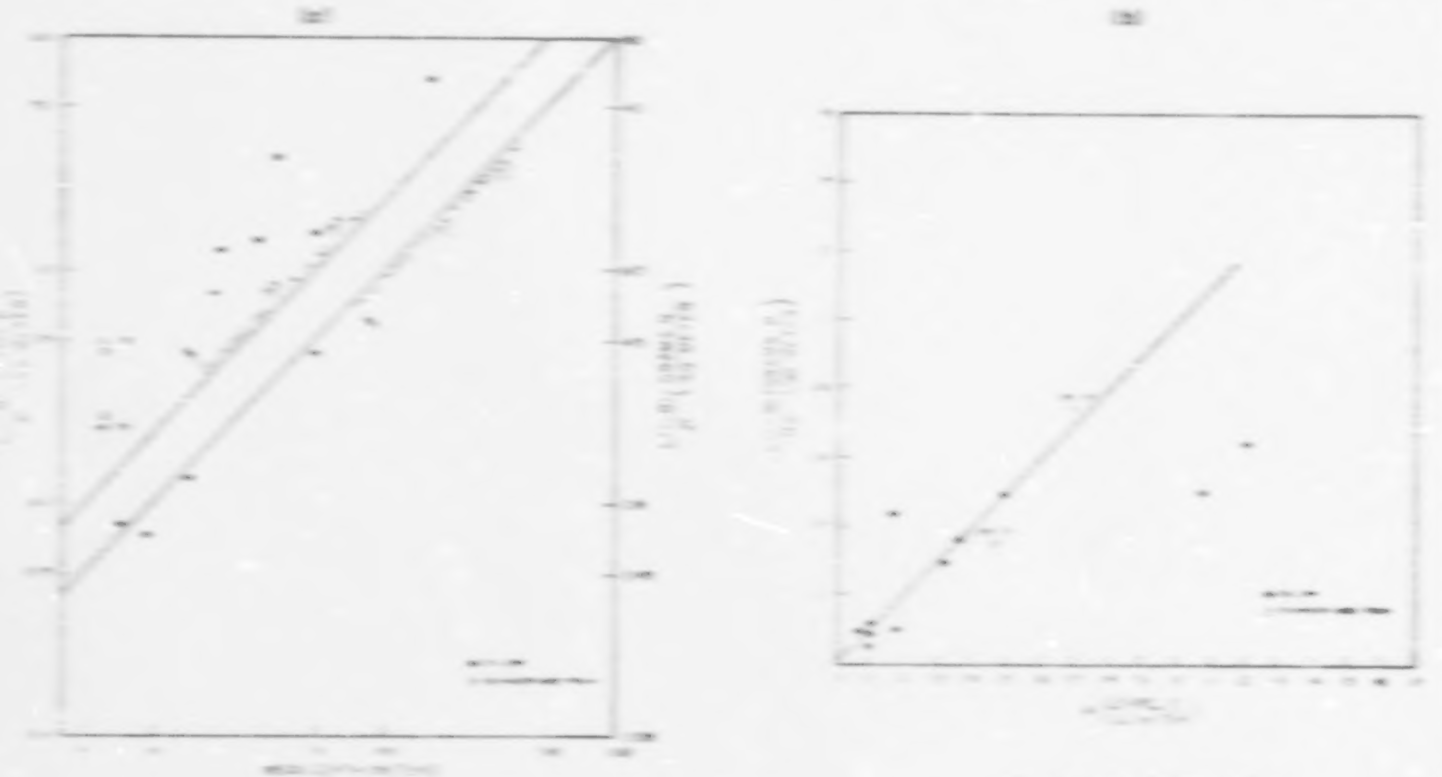
The empirical analysis developed by Vollenweider and expanded upon by Dillon for impoundment trophic classification assumes steady state and completely mixed conditions. The equation used to develop the model relates to the hydraulic flushing time, the phosphorus loading, the phosphorus retention ratio, the mean depth, and the phosphorus concentration of the impoundment as follows:

$$\frac{L(1 - R)}{\rho} = HP \tag{5-18}$$

where:

L = phosphorus loading ($lbs/ft^2/yr$)
R = fraction of phosphorus retained
ρ = hydraulic flushing rate (per year)
H = mean height (ft)
P = phosphorus concentration (lbs/ft^3).

The graphical solution is presented as a log-log plot of $\frac{L(1-R)}{\rho}$ versus H. Figure 5-24(a) is a reproduction of Dillon's work on several lakes in Canada. Lakes or impoundments which fall above the 20 ug/l concentration line tend to be eutrophic while those below the 10 ug/l concentration line tend to be oligtrophic.



GRAPHICAL SOLUTION TO THE DILLON APPROACH

TEST OF IMPOUNDMENT
STEADY STATE AND COMPLETE MIXING

FIGURE 5-24
RELATIONSHIPS FOR EVALUATING THE STATE OF A LAKE

In order to check the assumptions of steady state and complete mixing made in the Dillon approach, a plot of $\frac{L(1-R)}{H\rho}$ versus the P concentration should be developed. This plot, shown in Figure 5-24(b), is for various impoundments examined by Dillon. If the lake under study plots near the line shown on Figure 5-24(b) it appears that the assumptions associated with the Dillon techniques are valid. This indicates that the phosphorus levels in the impoundment are in equilibrium with the phosphorus inputs to the system. Satisfaction of this criteria would support the application of the Dillon technique to estimate the eutrophic status of the impoundment.

The application of the Dillon equation requires information on the physical characteristics of the impoundment and observed or calculated phosphorus loading data. The fraction of the phosphorus retained by an impoundment can be determined either empirically or theoretically. The empirical approach involves a mass balance calculation of the total inflow phosphorus, the total outflow phosphorus and the amount that remains in the impoundment. This difference may be estimated directly by collecting sinking material at the bottom of the impoundment and monitoring the phosphorus in the water column, or indirectly by monitoring the inflow and outflow phosphorus. This empirical approach requires data obtained through a comprehensive monitoring program which may not be feasible within the planning effort.

In general, lakes which appear to be in the eutrophic stage on the basis of the Vollenweider - Dillon analysis are candidates for more comprehensive analysis aimed at determining the principal cause of the nutrient enrichment so that alternative controls strategies can be developed. Chapters 2, 3 and 4 discuss various methods for determining nutrient sources in this case.

In situations where the Vollenweider - Dillon analysis would lead to the classification of the lake as oligotrophic, the analyst should be guided by other data in drawing conclusions regarding the status of the lake. Simplified assessments of impoundment water quality conditions such as this technique provide information having a level of reliability appropriate only for gaining a perspective of water quality conditions.

Results from these procedures should not be utilized for the design and implementation of control strategies.

5.5.3 Analysis Methods for Water Quality Evaluations in Lakes and Impoundments

An assessment of the expected level of pollutant concentrations in impoundments using a number of initial estimating techniques are presented in this section. The applicability and accuracy of these techniques are dependent upon how closely the characteristics of the actual impoundment fit the simplifying assumptions of the approach.

Three basic problem cases will be addressed. The first framework is applicable to run-of-river impoundments having small detention times. The system is assumed to be at steady state with one-dimensional plug flow and no vertical stratification. The second approach is applicable to large reservoirs and lakes wherein the impoundment is assumed to be completely mixed in the horizontal plane. Calculations for both vertically mixed and vertically stratified systems will be presented. The third set of estimates addresses pollutant concentrations in a two-dimensional, localized area. These are for impoundment areas where there is insignificant advective transport due to flow-through, wind currents, or density gradients, and where there may be significant concentration gradients around the point of discharge. Water quality estimates for a cove area adjacent to an impoundment will also be presented. These latter methods may also be used in analyzing estuaries and tidal rivers discussed in Section 5.4.2 of this manual.

For each system, analyses will be presented for conservative substances such as suspended solids, reactive substances such as coliforms and BOD, and coupled reactions such as BOD-dissolved oxygen deficit.

5.5.3.1 One-Dimensional Plug Flow Systems

With run-of-the-river type impoundments, the same analysis that is used to examine steady state water quality in free flowing streams and rivers may be applied to the impounded portion of the river. The basic reactions and equations are the same; the major difference is the decreased velocity and the correspondingly increased detention time in the impoundment.

The water is assumed to enter the impoundment with a flow Q, and conservative, reactive or coupled pollutant concentrations, C_0, L_0 and D_0, respectively. A constant loading rate, W, enters the impoundment at the upstream end and a distributed (nonpoint) load, ω, may enter throughout the length of the impoundment. For the analysis of the upstream point source, a constant or an expanding cross-sectional area may be used to characterize the geometry of the impoundment, whereas the analysis of the distributed load is limited to a constant cross-sectional area.

The solutions for pollutant concentrations as a function of distance, X, in the impoundment are shown in Table 5-20. The reaction rate of the first system is K_r, the reaction rate of the second system is K_a, and the rate describing the interaction between the two systems is K_d. For a BOD-DO deficit system where all of the BOD is removed by oxidation (rather than settling), $K_d = K_r$. Typical reaction rates are shown in Table 2-19.

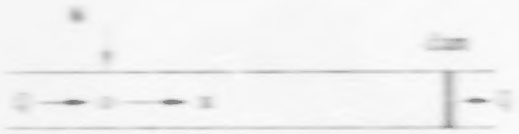
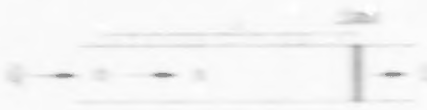
For the BOD-DO deficit system, K_a is the reaeration rate of dissolved oxygen in the river. It is best estimated in impoundments by using equation(5-6). Temperature correction of these values is accomplished using methods described in Section 2.6.3.4.

For the BOD-DO analysis, the magnitude of the ultimate oxygen demand (W_1) is entered in the BOD system and, as appropriate, the deficit loading is included in the DO deficit system (W_2). The ultimate oxygen demand is comprised of both carbonaceous and nitrogenous components which may be estimated to be 1.5 x W(BOD_5) and 4.57 x W(NH_3-N).

For the point source solutions of Table 5-20, f(x) will depend upon the distance-area relationship assumed for the impoundment. The relationship between cross-sectional area and distance downstream may have many functional forms. The most common for free-flowing streams is the constant cross-section, particularly when relatively short distances and small drainage areas are considered. A constant area is designated as

TABLE 5-29

SUMMARY OF STEADY STATE SOLUTIONS FOR POLLUTANT CONCENTRATIONS
IN A FLOW-THROUGH IMPOUNDMENT

	POINT SOURCE	DISTRIBUTED SOURCE
		
Conservative	$C = C_o + W/Q$	$C = C_o + w x/Q$
Reactive	$L = L_o e^{-K_r f(x)/\bar{U}_o} + W/Q\, e^{-K_r f(x)/\bar{U}_o}$	$L = L_o e^{-K_r x/U} + \frac{w}{AK_r} (1 - e^{-K_r x/U})$
Coupled	$D = D_o e^{-K_a f(x)/\bar{U}_o}$ $+ L_o \cdot \frac{K_d}{K_a - K_r} (e^{-K_r f(x)/\bar{U}_o} - e^{-K_a f(x)/\bar{U}_o})$ $+ W/Q \cdot \frac{K_d}{K_a - K_r} (e^{-K_r f(x)/\bar{U}_o} - e^{-K_a f(x)/\bar{U}_o})$	$D = D_o e^{-K_a x/U}$ $+ L_o \cdot \frac{K_d}{K_a - K_r} \cdot (e^{-K_r x/U} - e^{-K_a x/U})$ $+ \frac{w}{AK_r} \cdot \frac{K_d}{K_a - K_r} (\frac{K_r}{K_a} e^{-K_a x/U} - e^{-K_r x/U} + \frac{K_a - K_r}{K_a}$

A_0. For greater distances, larger drainage areas, or impounded rivers, the exponential and linear forms may be represented:

$$A(x) = \frac{A_0}{x_0} x \qquad (5\text{-}19)$$

$$A(x) = A_0 e^{ax} \qquad (5\text{-}20)$$

In these equations, A is the cross-sectional area at distance x, which is measured from the origin of the coordinate system. In equation (5-19) x_0 is the distance from a hypothetical origin to the location of A_0. In equation (5-20) A_0 is located at $x = 0$. In both cases, the location of A_0 may be arbitrarily assigned. Examples of constant, linearly and exponentially increasing representations of the area are shown in Figure 5-25. The appropriate expression for F(x) for use in Table 5-20 will depend upon the area-distance relationship assumed and is shown below.

Expression for F(x)

Area-Distance Relationship

	Constant	Linear Increase	Exponential Increase
F(x) =	x	$\frac{x^2 - x_0^2}{2x_0}$	$\frac{e^{ax} - 1}{a}$

where: a is an empirically developed constant.

Note that U_0, the velocity at the beginning of the impoundment, is used in the solutions presented in Table 5-20 and that for the linearly expanding case, $x = 0$ at the location which is a distance x_0 before the beginning of the impoundment. To apply the solution equations for a distributed source, a constant cross-sectional area must be assumed. If the area varies considerably, the impoundment may be divided into several constant-area segments and the analysis performed within each segment.

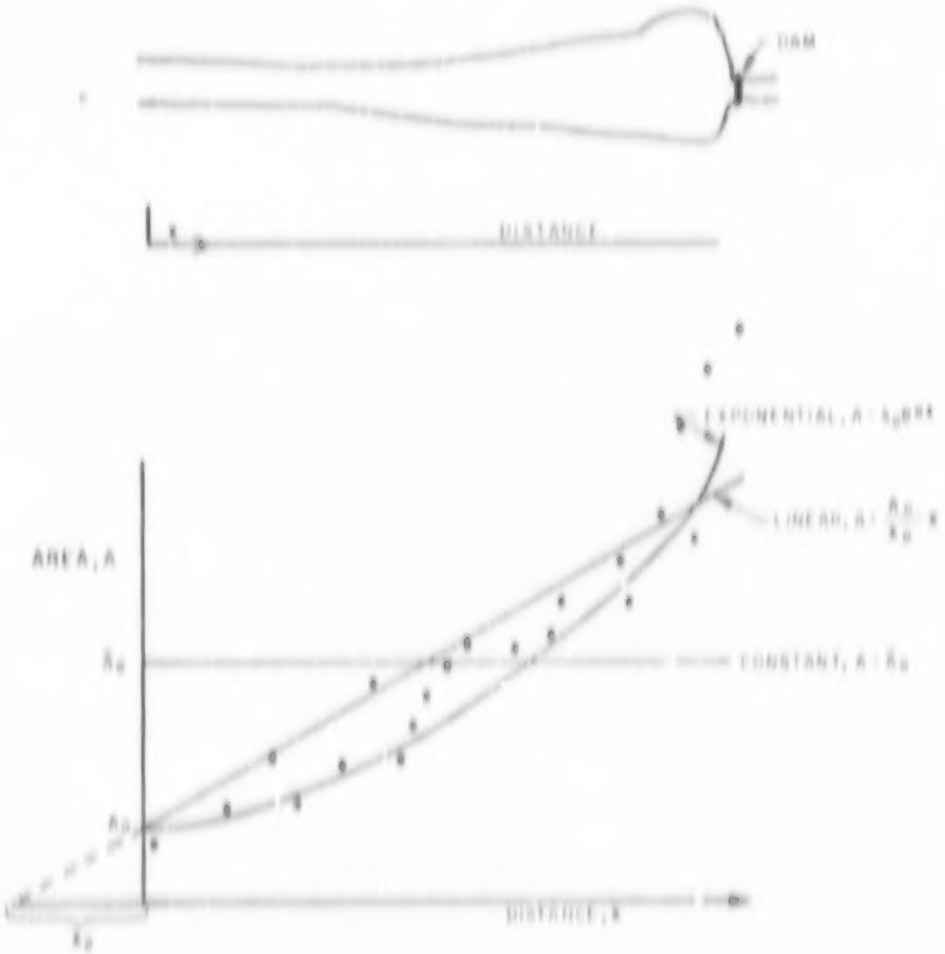


FIGURE 5-25
FUNCTIONAL AREA REPRESENTATIONS

5.5.3.1.1 Dissolved Oxygen Deficit Determination

The solutions for dissolved oxygen deficit obtained from Table 5-20 include only the effects of BOD loads and upstream BOD and DO deficit concentrations. They do not include the effects of the oxygen demand imposed on an impoundment by benthic material and algal respiration, and the input of dissolved oxygen from algal photosynthesis.

The components of the benthic material which exert an oxygen demand include inflow organic material, settled biomass, and chemical constituents which undergo oxidation-reduction at the sediment-water interface. Except for impoundment areas that receive direct discharges of settleable wastes, the benthal oxygen rate, S_B, may be estimated to be on the order of 0.3 to 3.0 gm O_2/m^2/day. Site specific data is normally required to refine the estimate of S_B. The monitoring appendix provides guidance in developing this type of data.

When algae are present in streams, there is a diurnal variation of dissolved oxygen due to varying photosynthetic oxygen production during the day. The primary factor that governs the photosynthetic oxygen production of algae is the quantity of solar radiation the algae receive. The average relative oxygen production may be estimated as follows:

$$\frac{P_{av}}{P_s} = \frac{2.718\, f}{K_e H\, T_p}\left(e^{-\alpha I_a/I_s} - e^{-I_a/I_s}\right) \qquad (5\text{-}21)$$

where:

$\alpha = e^{-K_e H}$

P_s is the light saturated rate of oxygen production

I_a is the average light intensity during the daylight portion of the day

I_s is the light saturated intensity

f is the number of hours of daylight

T_p equals twenty-four hours

K_e is the extinction coefficient

H is the river depth.

P_{av} in equation (5-21) is the average algal oxygen production over the entire day. The extinction coefficient ranges from 0.1 - 0.5 m^{-1} for very clear impoundments, from 0.5 to 2.5 m^{-1} for moderately turbid waters, and greater than 2.5 m^{-1} for very turbid waters.

The ability to calculate the absolute oxygen production rate depends upon the estimation of P_s, the light saturated rate of oxygen production. A correlation between P_s and the concentration of chlorophyll "a" taken as a measure of the algae population density may be used to estimate P_s:

$$P_s = 0.25\ Chl_a \qquad (5\text{-}22)$$

where:

P_s = mg oxygen produced/l/day
Chl_a = Chlorophyll "a" concentration in µg/l.

Thus, by measurement of the chlorophyll "a" concentration, the incident solar radiation I_a, the length of daylight f, the extinction coefficient k_e and the depth H, the average daily rate of photosynthetic dissolved oxygen production may be estimated.

Although algae produce oxygen by photosynthesis, they also utilize oxygen for respiration. The respiration rate, R, has also been related to chlorophyll "a" concentration:

$$R = r(Chl_a) \qquad (5\text{-}23)$$

where:

R = mg oxygen utilized/l/day
Chl_a = chlorophyll "a" concentration in µg/l
r = constant ranging from 0.005 to 0.030 with 0.025 a common value (22) corresponding to a 10 to 1 ratio of P_s to R.

The respiration rate is known to vary considerably and depends on the nutrient concentration and age of the culture. Hence the average daily algae respiration calculated from equation (5-27) is subject to some degree of uncertainty.

The estimates of the benthal oxygen demand, algal photosynthesis and respiration may be incorporated into the estimate of the average DO deficit by the following equation:

$$D = \frac{1}{K_a} \left(\frac{S_B}{H} - P_{av} + R\right) \left(1 - e^{-K_a f(x)/U_0}\right) \qquad (5\text{-}24)$$

This indicates the average in the impoundment, but not the diurnal variation around the average. The diurnal range of dissolved oxygen, Δ_D (mg/l), due to algal effects may be estimated (73) as:

$$\Delta_D = P_{av} \left(1 - \frac{f}{T_p}\right) \qquad (5\text{-}25)$$

Equation(5-25)requires that K_a be less than about 0.2 day^{-1} to be applicable. This should be true in most impoundments due to their depth and low velocities.

5.5.3.1.2 Location of Maximum DO Deficit Due to Point Source

Guidelines have been presented for estimating the steady state, spatial distribution of dissolved oxygen deficit in a run-of-the-river impoundment. The DO deficit due to the various sources may be added together and plotted as a function of distance, x, along the impoundment to determine the location and magnitude of the maximum DO deficit. A simpler approach is available for estimating the maximum DO deficit response due to a single point source. The maximum deficit, D_c, is:

$$D_c = \left(\frac{W}{Q}\right) \frac{K_d}{K_a} \left(e^{-\frac{K_r \ln(K_a/K_r)}{(K_a - K_r)}}\right) \qquad (5\text{-}26)$$

The determination of the location of the maximum DO deficit, x_c, depends upon the distance-cross-sectional area relationship assumed, and may be estimated for each as:

$$x_c = \frac{U_0}{K_r - K_a} \ln\left(\frac{K_r}{K_a}\right), \text{ for constant area} \qquad (5\text{-}27)$$

$$x_c = \sqrt{x_0^2 + \frac{2U_0 x_0}{(K_r - K_a)} \ln\left(\frac{K_r}{K_a}\right)}, \text{ for linearly expanding area} \qquad (5\text{-}28)$$

$$x_c = \frac{\ln\left(1 + \frac{aU_0}{(K_r - K_a)} \ln\left(\frac{K_r}{K_a}\right)\right)}{a}, \text{ for exponentially expanding area} \qquad (5\text{-}29)$$

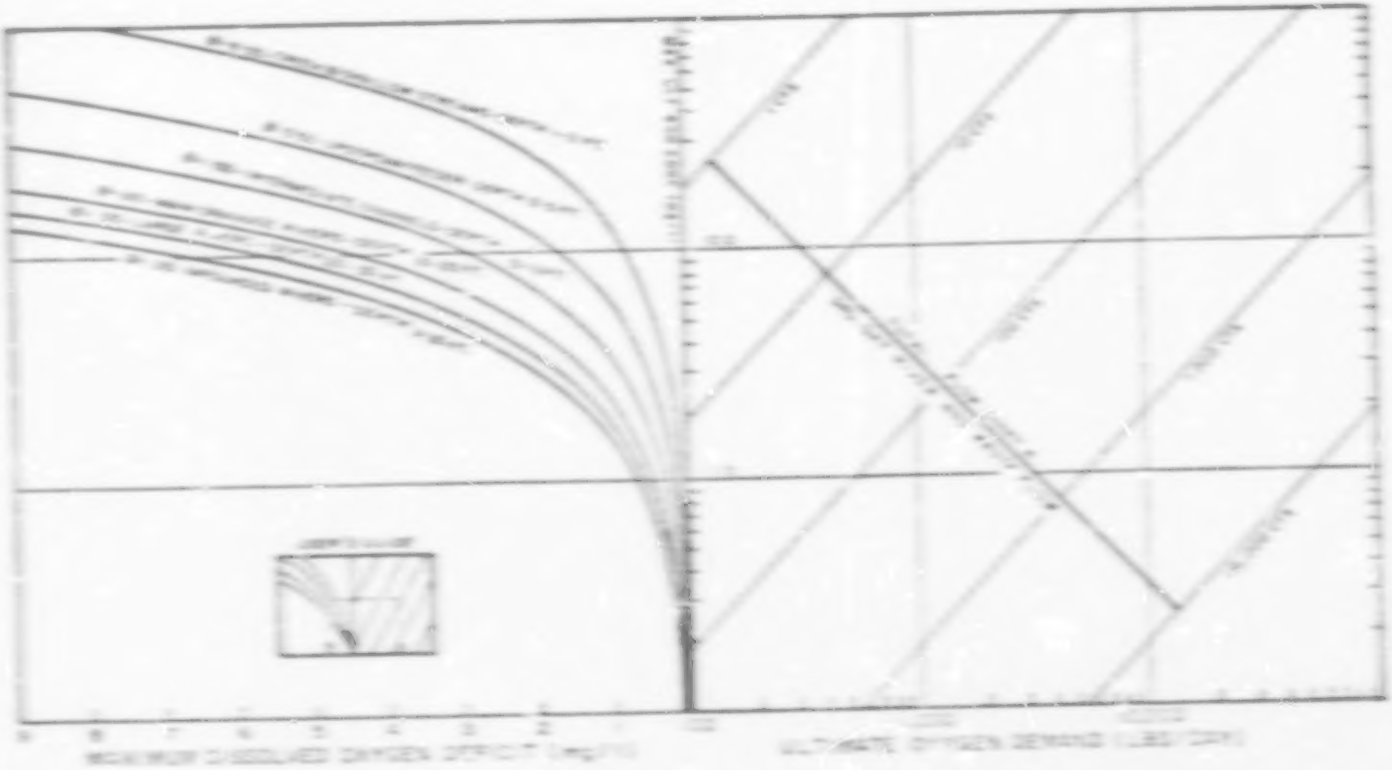
A graphical estimate of D_c due to the point source, W, may also be made using Figure 5-26 (8). The ultimate oxygen demand load is input on the upper right axis and the solution is determined by moving counterclockwise from the flow, to the maximum BOD concentration, to r, where $r = \frac{K_r}{K_a}$ (this analysis assumes $K_r = K_d$), to the maximum DO deficit. The location of the maximum deficit should still be calculated, however, to insure the maximum deficit occurs within the impoundment.

5.5.3.1.3 Determination of DO Concentration

Once the dissolved oxygen deficit has been determined, the DO concentration may be calculated. The dissolved oxygen saturation concentration, C_s, may be determined in streams, impoundments and estuarine systems from Figure 2-19(b) (pg. 2-82). Chloride concentrations may generally be assumed to be near zero in lakes and impoundments. The DO concentration, C, then equals C_s-D. Applications of the foregoing estimating technique are shown in Table 5-21.

5.5.3.2 Completely Mixed in the Horizontal Dimension

The second set of impoundment systems analyzed are the large reservoirs and lakes having long detention times. These impoundments are assumed to be completely mixed in the horizontal directions. Estimating procedures are presented for vertically mixed and vertically stratified systems. The impact of external pollutant loads can only be estimated for conservative or slowly reacting substances, as more rapidly reacting constitutents will not have a chance to be mixed throughout the impoundment. Estimates for dissolved oxygen concentrations are presented for assumed uniform rates of benthal demand, reaeration, algal photosynthesis, and respiration throughout the lake. The algal effects



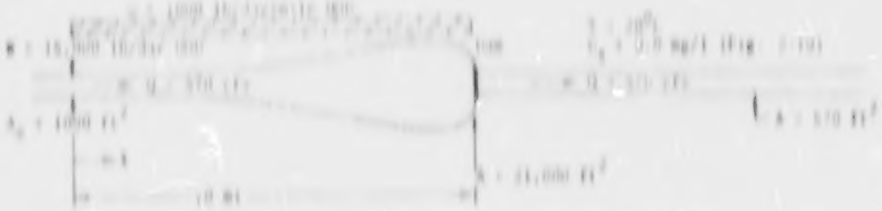
SOURCE:

FIGURE 5-35

SIMPLIFIED ASSESSMENT OF DISSOLVED OXYGEN DEFICIT IN IMPOUNDMENTS AND RIVERS

TABLE 5-21

EXAMPLE OF DO DEFICIT PROBLEM: RUN-OF-THE-RIVER IMPOUNDMENT AND DOWNSTREAM EFFECTS



Impoundment

Average H = 12 ft = 3.6 m
Average A = 5700 ft²
Average U = 0.1 ft/sec = 1.64 mi/day
$K_r = K_d = 0.25$ day^{-1}
$K_a = 0.16$ day^{-1}
P_{av} = 1.3 mg O_2/l/day
f = 14 hr
R = 0.4 mg O_2/l/day
S_B = 2 g O_2/m²/day
Assumed Upstream BOD and DO Deficit = 0

Downstream

Height Water Falls over Dam = H_d = 10 ft
Average H = 7 ft = 2.1 m
Average A = 570 ft²
Average U = 1 ft/sec = 16.4 mi/day
$K_r = K_d = 0.25$ day^{-1}
$K_a = 0.75$ day^{-1}
$P_{av} = R = S_B = 0$

Check Location of Maximum Deficit in Impoundment due to Point Source:

1) Assume Constant Area = 5700 ft² (Eq. 5-27)

$$x_c = \frac{1.64}{(0.25-0.16)} \ln\left(\frac{0.25}{0.16}\right) = 8.1 \text{ mi } (<10 \text{ mi, OK})$$

2) Assumed Exponentially Expanding Area from A_0 = 1000 ft² to A = 21,000 ft²,
Therefore: a = 0.30 (Fig. 5-17); $U_0 = \frac{570}{1000}$ = 0.57 ft/sec = 9.35 mi/day.

$$x_c = \ln\left[1 + \ln\left(\frac{0.25}{0.16}\right) \times \frac{0.30 \times 9.35}{(0.25-0.16)}\right] \div 0.30 = 9.0 \text{ mi } (<10 \text{ mi, OK}) \quad \text{(Eq. 5-28)}$$

Maximum Deficit in Impoundment from Point Source (Eq. 5-26)

$$D_c = \frac{15{,}000\ (\text{lb/day})}{570(\text{ft}^3/\text{s}) \times 5.4\left(\frac{\text{lb/day}}{\text{cfs} \cdot \text{mg/l}}\right)} \times \frac{0.25}{0.16}\left(e^{\frac{0.25}{(0.25-0.16)} \ln\left(\frac{0.16}{0.25}\right)}\right) = 2.20 \text{ mg/l}$$

TABLE 5-21
(Continued)

EXAMPLE OF DO DEFICIT PROBLEM: RUN-OF-THE-RIVER IMPOUNDMENT AND DOWNSTREAM EFFECTS

$x_c = 8.1$ mi (At location of maximum point source deficit)	$x = 10$ mi (In impoundment, at dam)
a) Deficit due to Point Source	
See preceding sheet $D = D_c = 2.20$ mg/l	See Table 5-20 $D = \frac{15{,}000}{570 \times 5.4} \times \frac{0.25}{(0.16 - 0.25)} \left(e^{\frac{-0.25 \times 10}{1.64}} - e^{\frac{-0.16 \times 10}{1.64}}\right)$ $= 2.16$ mg/l
b) Deficit due to Distributed Source (Table 5-20)	
$D = \frac{1000 \times 5.0 \left(\frac{mg/l}{10/11\ mi}\right)}{5700 \times 0.25} \times \frac{0.25}{(0.16 - 0.25)}$ $\times \left(\frac{0.25}{0.16} e^{\frac{-0.16 \times 8.1}{1.64}} - e^{\frac{-0.25 \times 8.1}{1.64}} + \frac{(0.16 - 0.25)}{0.16}\right) = 0.8$ mg/l	$D = \frac{1000 \times 1.0}{5700 \times 0.25} \times \frac{0.25}{(0.16 - 0.25)}$ $\times \left(\frac{0.25}{0.16} e^{\frac{-0.16 \times 10}{1.64}} - e^{\frac{-0.25 \times 10}{1.64}} + \frac{0.16 - 0.25}{0.16}\right)$ $= 1.1$ mg/l
c) Deficit due to Benthal Demand (Eq. 5-24)	
$D = \frac{1}{0.16} \left(\frac{2}{3.6}\right) \left(1 - e^{\frac{-0.16 \times 8.1}{1.64}}\right)$ $= 1.9$ mg/l	$D = \frac{1}{0.16} \left(\frac{2}{3.6}\right) \left(1 - e^{\frac{-0.16 \times 10}{1.64}}\right) = 2.2$ mg/l
d) Deficit due to Algae (Eq. 5-25)	
$D = \frac{1}{0.16} (-1.3 + 0.4) \left(1 - e^{\frac{-0.16 \times 8.1}{1.64}}\right)$ $= -3.1$ mg/l	$D = \frac{1}{0.16} (-1.3 + 0.4) \left(1 - e^{\frac{-0.16 \times 10}{1.64}}\right)$ $= -3.5$ mg/l
e) Dissolved Oxygen Concentrations without Algal Effects	
$DO = C_s - D = 9.0 - (2.2 + 0.8 + 1.9)$ $= 4.1$ mg O_2/l	$DO = 9.0 - (2.2 + 1.1 + 2.2)$ $= 3.5$ mg O_2/l
f) Dissolved Oxygen Concentrations with Algae	
Range of diurnal variation $= A_d = P_{av} (1 - f/24) = 1.3 (1 - 14/24) = 0.54$ mg/l (Eq. 5-25)	
f.1) Daily Average Concentration	
$DO_{av} = 9.0 - (2.2 + 0.8 + 1.9 - 3.1)$ $= 7.2$ mg O_2/l	$DO_{av} = 9.0 - (2.2 + 1.1 + 2.2 - 3.5)$ $= 7.0$ mg O_2/l
f.2) Minimum Daily Concentration	
$DO_{min} = DO_{av} - A_d/2 = 7.2 - 0.54/2$ $= 6.9$ mg O_2/l	$DO_{min} = 7.0 - 0.54/2$ $= 6.7$ mg O_2/l

may be qualitatively related to external nutrient loads using the Vollenweider and Dillon techniques previously presented.

The first case analyzed is the completely mixed (horizontally and vertically) lake with a conservative or slowly reacting (in relation to the detention time) substance. Examples of slowly reacting substances which may be relevant for this type of analysis include pesticides and radioactive materials. The equations for the lake concentration are shown in Table 5-22. A constant pollutant load, W_0 is assumed to enter the lake. The lake has a volume, V, an outflow, Q, initial conservative and reactive pollutant concentrations, C_0 and L_0, and for the reactive substance, a reaction rate K_r. If the inflow is estimated from the upstream drainage area, the net evaporation should be subtracted to determine Q. The impoundment does not reach a steady state rapidly if the detention time is long, and the time variable equations of Table 5-22 may be used to estimate the buildup over time. Also shown is the lake response to a load increasing or decreasing linearly with time. Since this loading condition never reaches a constant value, the receiving water concentrations never reach a steady state concentration. Application of these equations are shown in Table 5-23.

5.5.3.2.1 Vertical Stratification

Stratification occurs when the flow through an impoundment is insufficient to overturn the temperature and density gradients discussed in Section 5.5.1, due to sources and sinks of heat, such as solar radiation, evaporation and conduction. The temperature patterns in a lake follow a seasonal pattern, and prediction of the temperature profile requires analysis techniques beyond the scope of this manual.

In impoundments with long detection times, concentrations of solids-associated pollutants vary with depth due to settling. This process may be characterized for conservative substances by the following equation(34):

$$C(Z) = C_0 e^{ZV_s/E_v} \qquad (5-30)$$

TABLE 5-22

CONCENTRATIONS IN LARGE, COMPLETELY MIXED IMPOUNDMENT

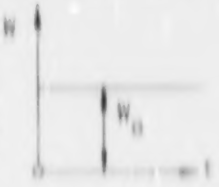
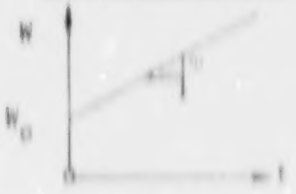
	Constant Load	Linearly Increasing or Decreasing Load
	 $W = W_0$	 $W = W_0 \pm \alpha t$
Conservative - Concentration vs. Time	$C_0 e^{-\frac{Q}{V}t}$ $+ \frac{W_0}{Q} (1 - e^{-\frac{Q}{V}t})$	$C_0 e^{-\frac{Q}{V}t} + \frac{W_0}{Q} (1 - e^{-\frac{Q}{V}t})$ $\pm \frac{\alpha V}{Q^2} (\frac{Q}{V}t + e^{-\frac{Q}{V}t} - 1)$
- Steady State	$\frac{W_0}{Q}$	
Slowly Reactive $(K_r << \frac{Q}{V})$ Note: $a = \frac{Q}{V} + K_r$ - Concentration vs. Time	$L_0 e^{-at}$ $+ \frac{W_0}{aV} (1 - e^{-at})$	$L_0 e^{-at} + \frac{W_0}{aV} (1 - e^{-at})$ $\pm \frac{\alpha}{a^2 V} (at + e^{-at} - 1)$
- Steady State	$\frac{W_0}{aV}$	

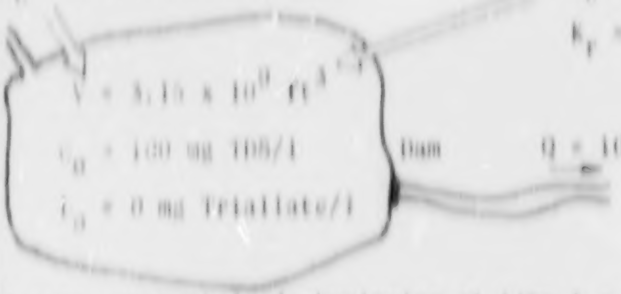
TABLE 5-23

EXAMPLE, COMPLETELY MIXED IMPOUNDMENT
(See Table 5-22)

Conservative, TDS
W_c = 108,000 lb TDS/day

Slow Decaying Pesticide, Triallate
W_i = 1080 lb Triallate/day

$K_r = 0.23\ \text{year}^{-1} = 6.3 \times 10^{-4}\ \text{day}^{-1}$



Assume constant loads beginning at time t = 0

1) Equilibrium TDS Concentration, $C_e = \frac{W_c}{Q}$

$$C_e = \frac{108{,}000}{100 \times 5.4} = 200\ \text{mg/l}$$

2) Buildup over time of TDS

$$Q/V = \frac{1}{\text{detention time}} = 1\ \text{year}^{-1}$$

$$C = C_0 e^{-Qt/V} + \frac{W_c}{Q}\left(1 - e^{-Qt/V}\right) = 100\,e^{-t} + 200\,(1 - e^{-t})$$

t (years)	C (mg TDS/l)	t (years)	C (mg TDS/l)
0	100	2.0	187
0.5	139	3.0	195
1.0	163		

3) Equilibrium Triallate Concentration, $i_e = \frac{W_i}{aV}$

$$a = (1 + 0.23) = 1.23\ \text{year}^{-1}$$

$$i_e = 1080/(1.23 \times 3.17 \times 10^{-8}\ \text{year/sec} \times 3.15 \times 10^9 \times 5.4)$$

$$= 1.6\ \text{mg Triallate/l}$$

where $C(Z)$ is the concentration at a depth Z, C_0 is the concentration at the surface, V_s is the settling rate, and E_v is the vertical diffusion coefficient. Settling rates for suspended solids range from 0.1 to 30 m/day depending on the density and particle size (25) while E_v will range from 0.1 to 10 m^2/day with 1 m^2/day frequently used (26). Examples of exponentially increasing concentrations with depth are shown for Lake Livingston, Texas in Figure 5-27.

Large impoundments also tend to be vertically stratified with respect to dissolved oxygen concentrations, because the lake surface is a source of oxygen from reaeration, the bottom is a sink of oxygen due to benthal demand, the production of oxygen from algal photosynthesis varies with depth due to decreasing light penetration with depth, and there is limited vertical exchange of oxygen in the water column. If the lake is considered to have one zone (that is, a constant E_v), the dissolved oxygen deficit profile may be estimated by the following (23):

$$D(Z) = \frac{S_B}{K_L}\left(1 + \frac{K_L Z}{E_V}\right) + \frac{HR}{K_L}\left(1 + \frac{K_L Z}{E_V}\left(1 - \frac{Z}{2H}\right)\right) - \frac{P_a r}{K_L K_e T_p}\left[1 - e^{-K_e H} + \frac{K_L}{E_V}\left(\frac{1 - e^{-K_e Z}}{K_e} - Ze^{-K_e H}\right)\right] \qquad (5\text{-}31)$$

Guidelines for estimating S_B, R, P_a, $\frac{1}{T_p}$, K_e, and E_v have been previously presented, and may also be applied here. Note this simplification assumes $\frac{I_a}{I_s} = 1$, (see equation (5-21)) and there is some error when it does not." K_L is the oxygen transfer coefficient ($K_L = HK_a$) and may be estimated as follows for the horizontally mixed impoundments (27):

$$K_L = 0.362\, s_w^{1/2} \quad \text{for } s_w < 5.5 \text{ m/sec}$$
$$K_L = 0.0277\, s_w^{2} \quad \text{for } s_w \geq 5.5 \text{ m/sec} \qquad (5\text{-}32)$$

where K_L is measured in m/day and s_w is the wind speed in m/sec. An application of this technique is shown in Table 5-24. Note that this is only recommended for an initial order-of-magnitude estimate, and more sophisticated time variable models are required for a more accurate estimate.

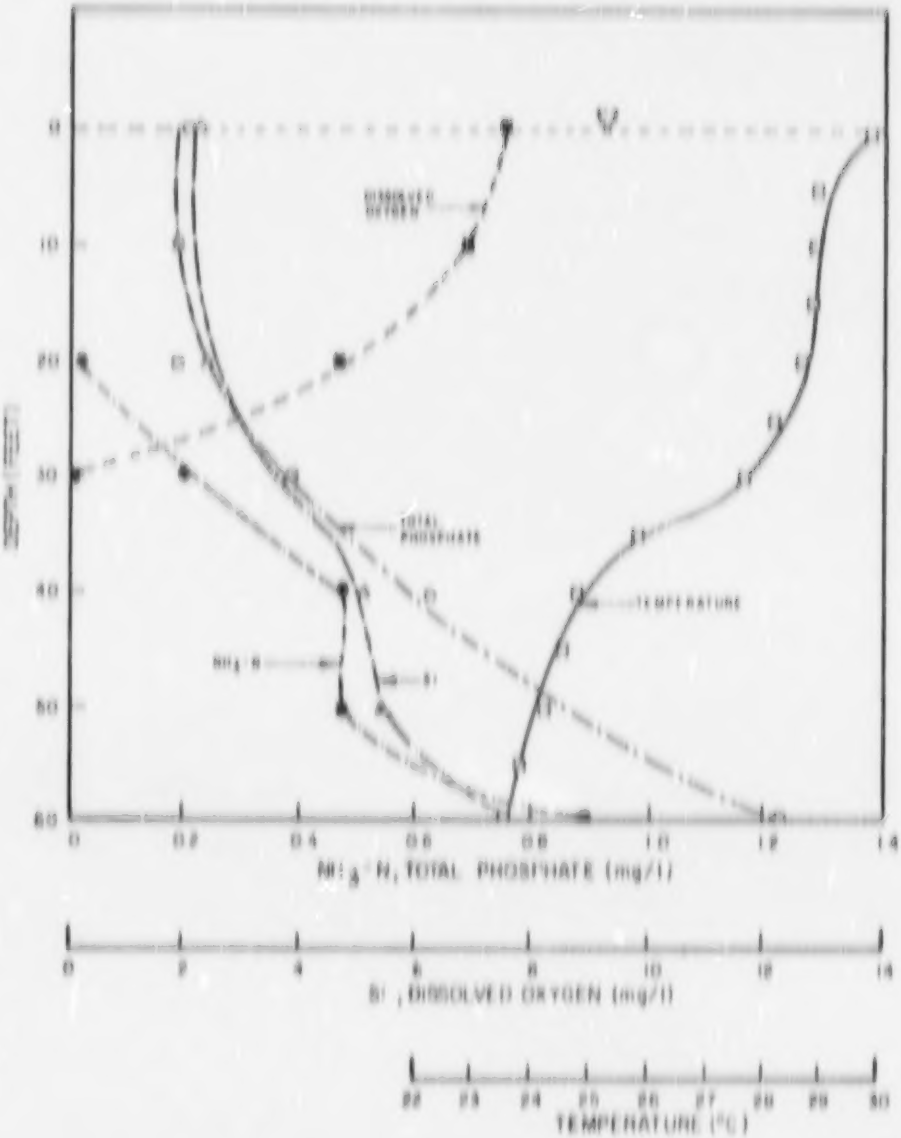
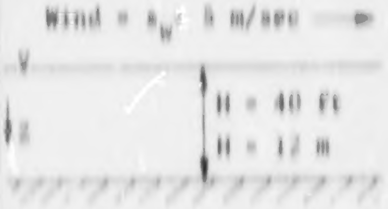


FIGURE 5-27
WATER QUALITY VARIATION WITH DEPTH IN LAKE LIVINGSTON, TEXAS

TABLE 5-24

EXAMPLE HORIZONTALLY MIXED IMPOUNDMENT
DO DEFICIT PROFILE



f = 14 hr $S_B = 0.5$ g O_2/m^2/day

T_p = 24 hr $E_v = 1.0$ m^2/day

Chl_a = 20 ug/l

$K_e = 0.2$ ft^{-1} = 0.67 m^{-1}

T = 20°C (Assume Uniform), C_s = 9.0 mg/l

---

1) Estimate K_L (Eq. 5-32)

$$K_L = 0.362\ (5)^{1/2} = 0.81 \text{ m/day}$$

2) Estimate P_s (Eq. 5-22)

$$P_s = 0.25\ (20) = 5.0 \text{ mg } O_2\text{/l/day}$$

3) Estimate R (Eq. 5-23)

$$R = 0.025\ (20) = 0.50 \text{ mg } O_2\text{/l/day}$$

---

4) Determine DO Deficit at Different Depths (Eq. 5-31)

$$D(Z) = \frac{0.5}{0.81}\left(1 + \frac{0.81\ Z}{1.0}\right) + \frac{0.50 \times 12}{0.81}\left(1 + \frac{0.81\ Z}{1.0}\left(1 - \frac{Z}{2 \times 12}\right)\right)$$

$$- \frac{5.0 \times 14}{0.81 \times 0.67 \times 24}\left[1 - e^{-0.67 \times 12} + \frac{0.81}{1.0}\left(\frac{1 - e^{-0.67Z}}{0.67} - Ze^{-0.67 \times 12}\right)\right]$$

$$D(Z) = -3.84 + 6.5Z - 0.25Z^2 + 6.5e^{-0.67Z} \quad (Z \text{ in meters})$$

Z (meters)	Def (mg/l)	Z (meters)	Def (mg/l)
0	2.7	3	14.3(anaerobic)
1	5.7	>3	(anaerobic)
2	9.9		

The equation presented for the DO deficit profile assumes one zone in the lake. Often the stratification becomes so severe that two zones are formed when a thermocline divides the upper warmer layer and the lower colder layer of the lake. When this occurs, the lower layer may become anaerobic, resulting in regeneration of inorganic nitrogen and phosphorus from the sediment. The DO profile shown for Lake Livingston, Texas, in Figure 5-27 demonstrates the increasing deficit with depth, leading to anaerobic conditions in the lower portion of the water column. In the lake, the thermocline occurs at a depth of approximately 30 feet.

5.5.3.3 Localized Pollutant Concentrations

The third set of problems analyzed deal with the pollutant concentrations around a localized load to an impoundment. The impoundment is assumed vertically mixed in the vicinity of the waste source and mass is assumed to be transported in the impoundment only by dispersion (insignificant effect from flow-through or currents). The load, W, enters the impoundment over a width, 2a, and a depth, H, the depth of the impoundment in the vicinity of the waste source. Figure 5-28 depicts the problem and the curve (28) for estimating the concentration at the shoreline of the impoundment at the midpoint of the load, C(0,0). The load may be due to a tributary, a cove where a treatment plant discharges, or a distributed source such as septic tanks or a marsh area. If the load is assumed to be distributed, that is equivalent to w(lb/day/mile) in Table 5-20 for the run-of-the-river impoundment, W may be calculated as W = w·2a. The dispersion coefficient, E, is for dispersion in the horizontal directions. E will range generally from 10^4 to 10^7 m^2/day in lakes, and the lower values are typical of the near-shore region. Once C(0,0) has been determined, the concentration at points along the shore may be estimated from Figure 5-29. The concentration at a given distance perpendicular to the shore (along the x axis) will be less than the concentration at the same distance along the shore (along the y axis). Therefore, Figure 5-29 may also be used for a conservative estimate of pollutant concentration profiles perpendicular to the shoreline.

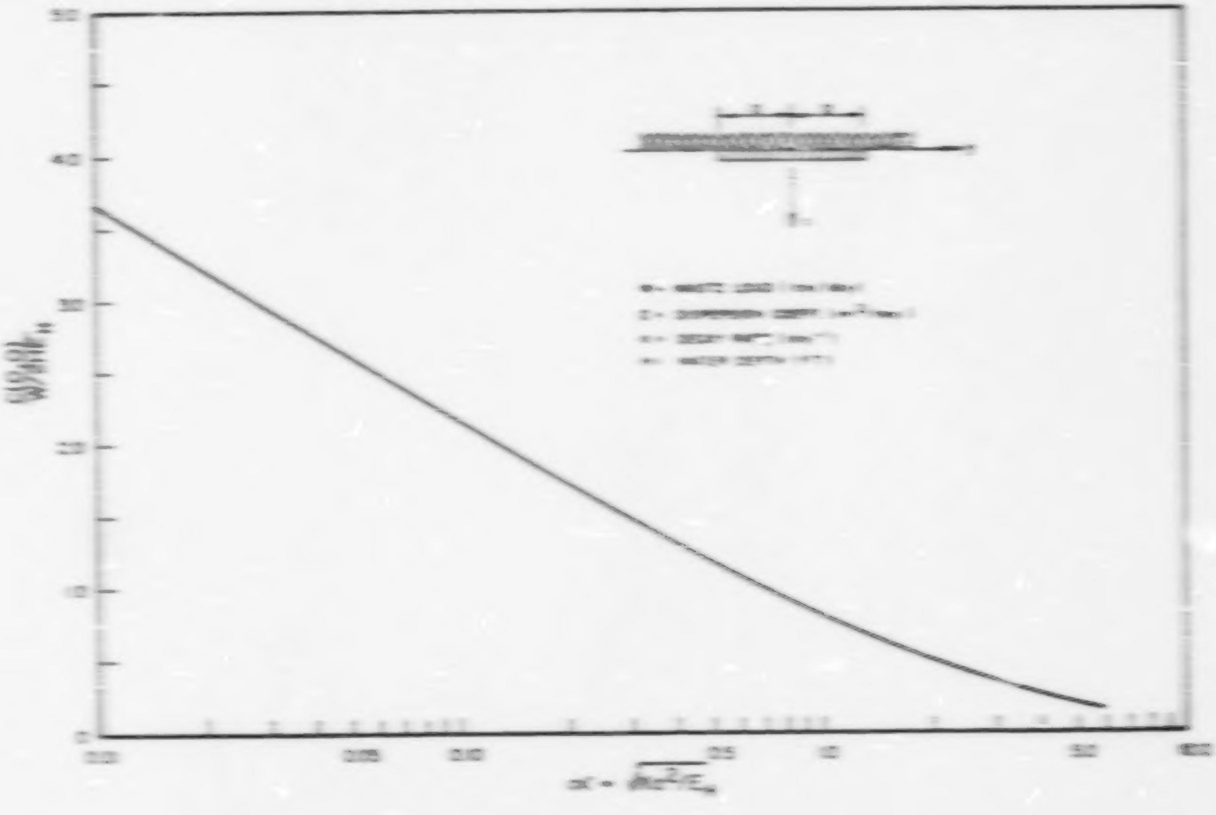


FIGURE 5-28
MAXIMUM ALONGSHORE CONCENTRATION

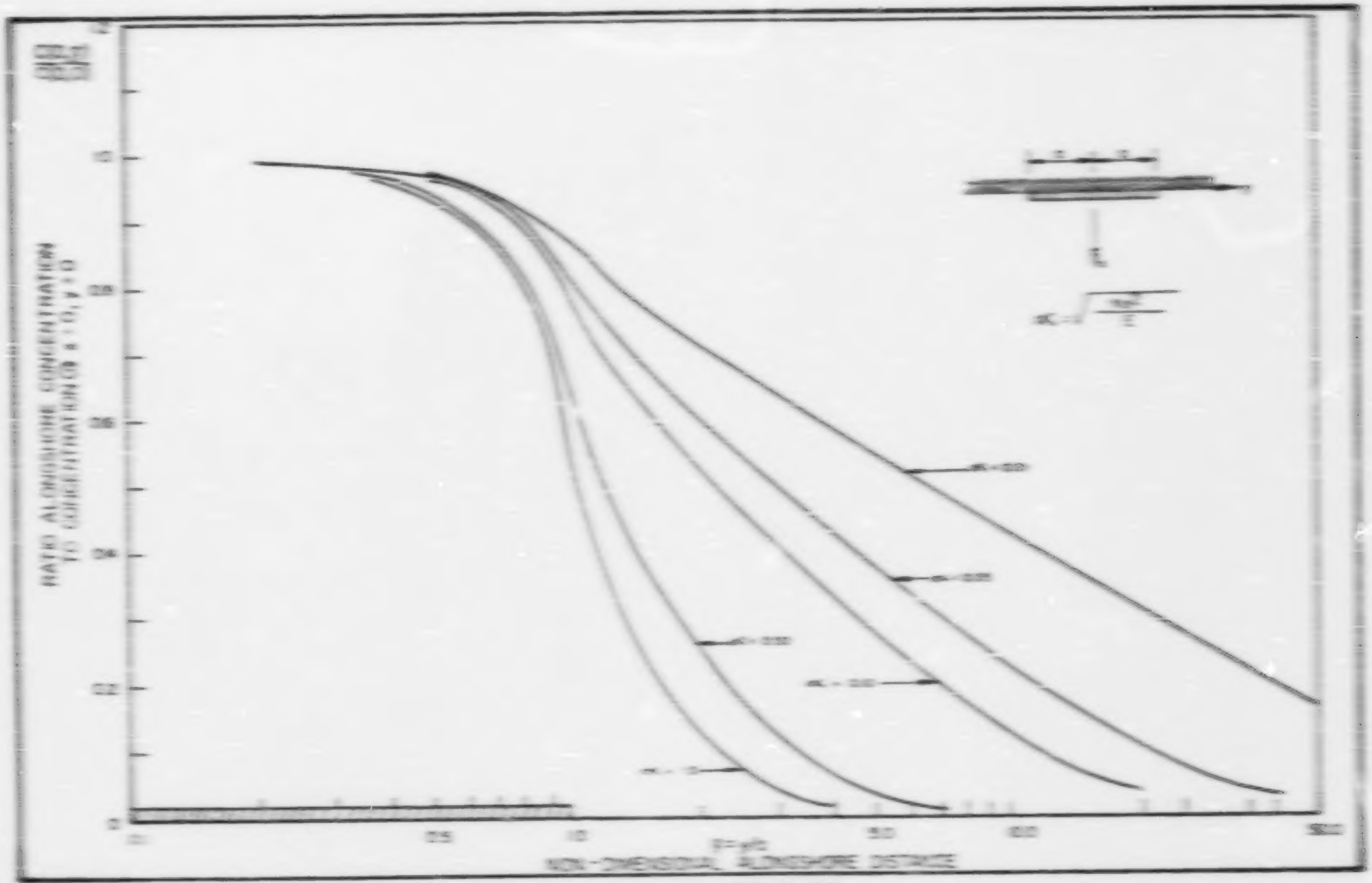


FIGURE 5-29

ALONGSHORE CONCENTRATION ESTIMATE

To determine the concentration of a coupled substance, such as DO deficit, the following equation may be used (29):

$$D = \frac{K_d}{K_a - K_r} (C_1 - C_2) \qquad (5\text{-}33)$$

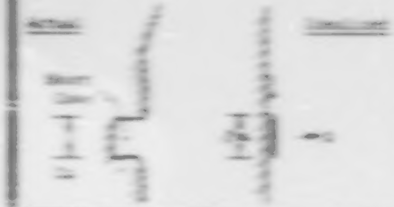
where D is the deficit at the point of interest, C_1 is the concentration of BOD calculated at the point of interest using Figures 5-28 and 5-29, and C_2 is the BOD that would be calculated at the point of interest with $K_r = K_a$. Applications of this technique are shown in Table 5-25.

If a wasteload is discharged into a short cove near the interface of the impoundment, the previous analysis may be used. If the cove is long and the discharge is far from the impoundment interface, however, significant reaction may occur in the cove. In this case, the following procedure should be employed.

The waste load is assumed to enter the water at the upstream end of the cove as shown in Table 5-26. The equations for each case for the reactive and sequentially reactive concentrations in the cove are shown in the respective Tables. Note that, as before, BOD and DO deficit loads may both be analyzed. The pollutant is assumed to be transported within the cove by advection (Q) and dispersion (E). The dispersion coefficient should be of approximately the same magnitude as within the impoundment: $E = 10^4$ to 10^7 m^2/day with the higher values appropriate for coves with significant advective flow. The concentration from the load is assumed to be reduced to nearly zero (5 percent of the maximum cove concentration) at the cove-impoundment interface, and thus the load has a negligible effect on the main portion of the impoundment. For this assumption to be true the cove must be "long", that is, the distance from the load to the impoundment, b, must be greater than $3/|j_1|$ for the reactive analysis (j_1 is defined in Table 5-26) and b must satisfy the requirements indicated in Figure 5-30 for the coupled DO deficit analysis.

The reaction rates may be taken from Table 2-18 and the reaeration may be estimated from the wind speed in equation(5-32)for coves with an advective velocity ($U = \frac{Q}{A}$) less than 0.1 ft/sec, and from equation(5-6)

[illegible]

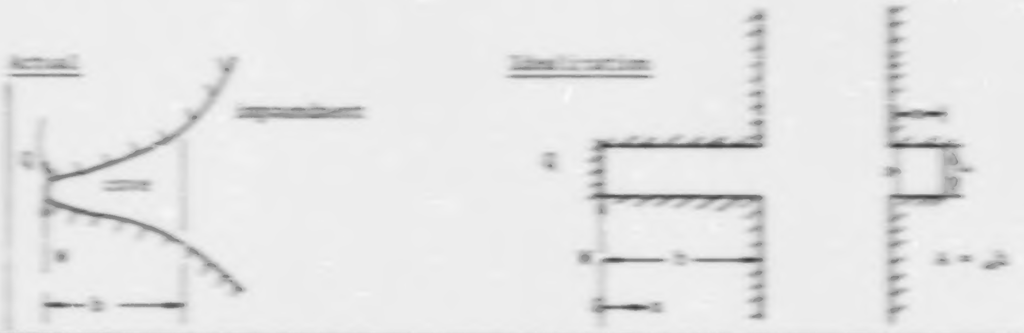


[illegible]

TABLE 3-29

EQUATIONS FOR LONG COVE ANALYSIS

"Long" cove



Reactive $b \ge \frac{2}{\lvert j_1 \rvert}$	$L = L_0 e^{j_1 x}$, where $L_0 = \frac{W_1}{Q} \cdot \frac{2}{1+m_1}$
Sequentially Reactive $b \ge x_{MIN}$ see Fig. 3-30	$D = D_0 e^{j_2 x} + \frac{K_{12}}{K_2 - K_1} \cdot L_0 \left(e^{j_1 x} - \left(\frac{1+m_1}{1+m_2}\right) e^{j_2 x} \right)$, where $D_0 = \frac{W_2}{Q} \cdot \frac{2}{1+m_2}$ $D = D_{MAX}$ occurs at $x = x_c = \ln \left(\frac{1+m_1}{1+m_2}\right) \left(\frac{1+m_2}{1+m_1} - \frac{D_0}{L_0} \cdot \frac{K_2 - K_1}{K_{12}}\right) \div \frac{u}{2E} (m_2 - m_1)$

Description of symbols with typical units

Q=flow (cfs)	K_1=decay rate, system 1 (e.g. BOD) (day^{-1})	$m_i = \sqrt{1 + 4K_i E/u^2}$
Velocity u = $\frac{Q}{A}$ (fps)	K_2=reaction rate, system 2 (e.g. reaeration rate)	$j_i = (u/2E)(1-m_i)$
A=cross-sectional area (ft^2)	K_{12}=reaction rate between systems 1 & 2, (e.g. deoxygenation rate K_d) (day^{-1})	E = dispersion coeff. (mi^2/day)
W=mass discharge (lb/day)		

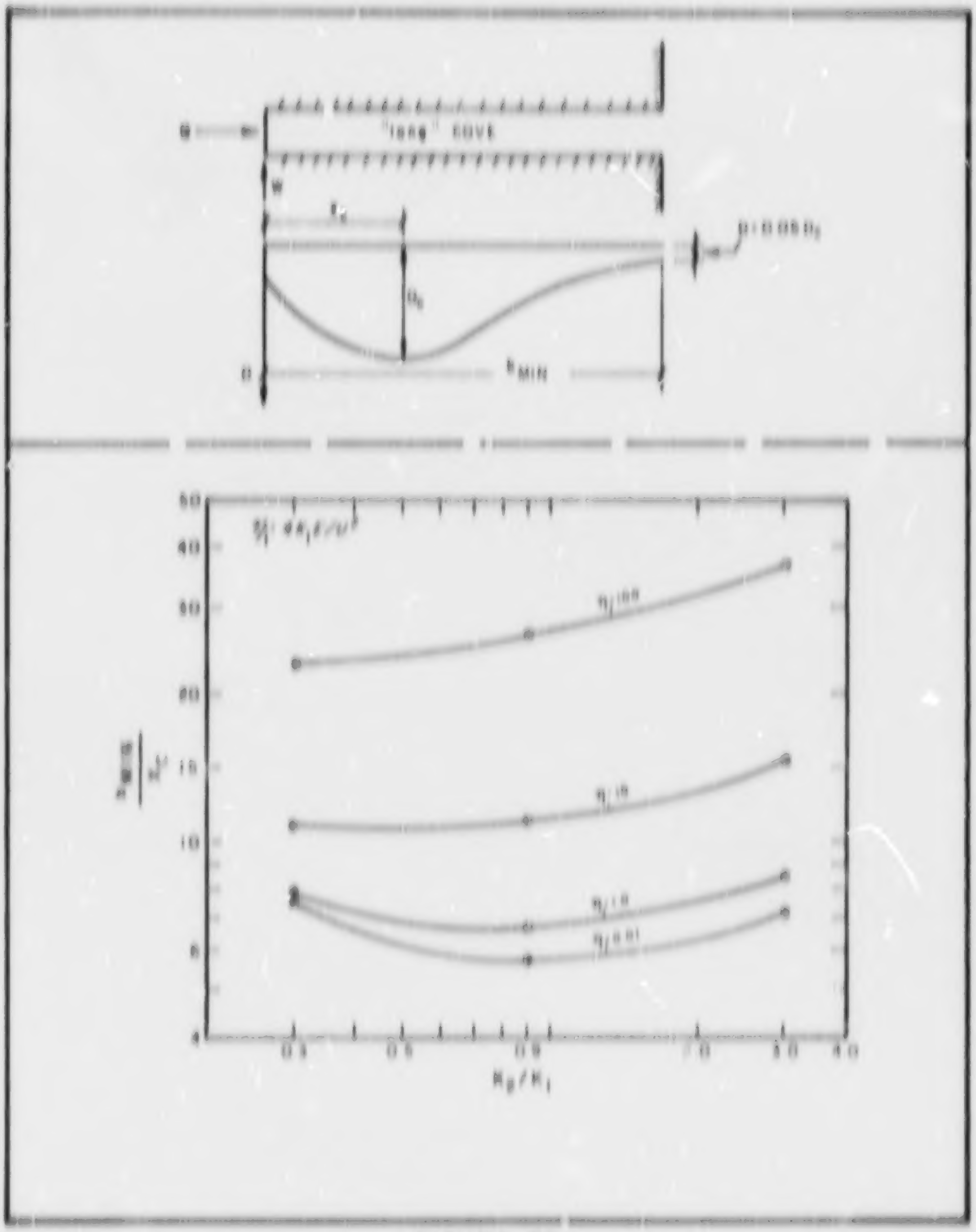


FIGURE 30
MINIMUM LENGTH FOR DISSOLVED OXYGEN DEFICIT
ANALYSIS IN "LONG" COVE

when the advective velocity is greater than 0.1 ft/sec. Applications of the "long" cove analysis are shown in Table 5-27.

5.5.3.4 Water Quality Downstream of Impoundments

The degree to which impoundment releases impact downstream water quality depends upon the quality of the impounded water at the dam and the characteristics of the downstream channel. The release is assumed to have one-dimensional plug flow, and the equations for conservative, reactive and coupled concentrations in Table 2-17 may be applied. Another consideration in the downstream analysis is the manner of release from the impoundment. If the water flows over a dam, there will be reaeration which decreases the dissolved oxygen deficit. This effect may be estimated by the following equation:

$$D_a - D_b = 0.037\ H_d D_a \qquad (5\text{-}34)$$

where D_a is the deficit above the dam (in the impoundment), D_b is the deficit below the dam, and H_d is the height the water falls (ft). This formulation was developed for the Mohawk River and Barge Canal, and is valid for dams up to 15 feet high and temperatures in the range of 20° to 25°C. For example, if the deficit concentration above the dam is 2.0 mg/l and the dam height is 8 feet, the dissolved oxygen deficit concentration below the dam is estimated to be:

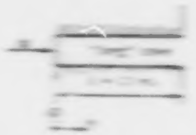
$$D_b = 2.0 - 0.037(8)(2.0)$$

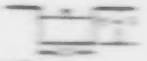
$$D_b = 1.4 \text{ mg/l}$$

If the impoundment release is from the bottom of the dam, other factors must be considered. As previously indicated, the deeper layer of impoundments, particularly larger stratified reservoirs, tend to be colder, lower in dissolved oxygen, higher in solids related pollutants, and may possibly contain anaerobic by-products. Releases of this type may result in serious downstream water quality problems, and should be carefully monitored.

TABLE 5-[illegible]

EXAMPLE OF LONG CONE ANALYSIS





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APPENDIX D

MONITORING REQUIREMENTS, METHODS, AND COSTS

D.1 Introduction

The nation's waters are as mixed and varied as its population and, just as there is no single measure of human health, there is no single measure of water quality. Furthermore, the nation's waters themselves (ground waters, streams, lakes, estuaries, and coastal waters) vary considerably in size, geological features, flow characteristics, climate and meteorological influences, and the type and extent of human impacts on them, and all these factors have a bearing on water quality.

Most definitions of water quality today are use-related, and each water use is sensitive to different pollution types and levels. For example, sufficient dissolved oxygen is critical to fish and other aquatic life but of little significance to drinking water supplies or swimming. On the other hand, coliform bacteria counts are a classical water pollution measure for human contact or ingestion but have little significance for most industrial uses or aquatic life. Even for the same parameter, the critical concentration for which one use begins to be impaired may be quite different from the level at which another use is affected. Thus, water quality monitoring - the collective activity that allows determination of the suitability of a particular water source for a specific use - is heavily use dependent. It is one thing to evaluate the lower Mississippi River as a drinking water supply and quite another to evaluate Lake Erie for swimming, a small stream in Michigan for trout fishing, or the South Platte River for irrigation. A different monitoring effort would be required for each.

D.1.1 How to Use This Appendix

In view of the foregoing, this Appendix cannot be a cookbook. Its overall objective is to provide the 208 planner with a range of information, considerations, and techniques that will allow him to design and implement a water quality monitoring program that is suited to his particular requirements. As indicated in Chapter 1 of this Manual, special emphasis is placed on equipment and methods suitable for storm-generated discharges.

The organization of this Appendix is indicated in Table D-1. By referring to it, the reader can locate information on the topic of immediate interest, e.g., where to look for available water quality data, how to select test catchments for stormwater model calibration and verification, how to choose an automatic sampler, etc. The topical organization is intended to support the chapters in the main body of this Manual by allowing quick reference to specific information, but it is recommended that this entire Appendix be read and understood thoroughly before implementation.

D.1.2 Purposes and Objectives of 208 Monitoring

The broad objective of a monitoring activity is to provide information upon which decision-makers can act. A more specific statement of objectives is required, however, for design and implementation of a monitoring effort. Examples of more specific monitoring objectives of interest to 208 agencies include:

1. Establishing baseline conditions
2. Determination of assimilative capacities of streams
3. Following the effects of a particular project or activity
4. Pollutant source identification
5. Long-term trend assessment
6. Waste load allocation
7. Projecting future water characteristics

TABLE D-1. ORGANIZATION OF APPENDIX D

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These monitoring objectives include both point and nonpoint source considerations involving variable and intermittent as well as continuous flows (see Chapter I of this Manual). In particular, Section 208 of PL 92-500 has focused money and attention on stormwater runoff and the need for urban runoff quality planning. The goals of such planning efforts are to define the runoff problem, identify potential solutions and costs, and measure the effectiveness of solution alternatives versus costs. Planning of this nature requires a method of evaluation that can provide comprehensive and areawide analysis, including the prediction of alternative futures. Mathematical models represent a developing tool that can be used by planners to meet these needs (see Appendix A). Such models require field data for their calibration and verification, and monitoring for this objective, along with problem assessment monitoring, will be emphasized in this Appendix.

A detailed listing of some USEPA uses for monitoring information is given in Table D-2. From a review of this table, it is readily apparent that a proper understanding of what is sought is paramount in the design and implementation of any given monitoring activity. Furthermore, the objectives should be reduced to writing, not only to ensure careful consideration of what they actually should be and help prevent misunderstandings by those involved, but also to set the limits, and thus discourage the pursuit of interesting but nonessential hypotheses. These objectives will also provide a basis for measuring the extent to which the results of the effort meet the needs that justified the undertaking.

To illustrate the form such objective statements might take, several examples will be given. These were taken from actual 208 program efforts that are being designed and implemented now.

The stated objective for an instream sampling survey is to provide water quality and flow data for calibration and verification of a continuous water quality simulation model which will be used to simulate existing and future

TABLE D-1
SOME USEPA USES OF MONITORING INFORMATION

Develop/revise water quality standards

Develop/revise 303 basin plans

Develop/revise 208 areawide plans

Develop/revise 201 facilities plans

Document progress toward achievement/maintenance of ambient standards and legislative goals

Monitor primitive areas for background levels and significant deterioration

Development of baseline information

Model validation/development

Develop health research/control techniques

Develop/evaluate Environmental Impact Statements

Develop/revise effluent standards

Formulate/revise discharge permits

Determine permit compliance

Develop/revise drinking water standards

Develop/revise pesticides monitoring plan

Develop/revise toxic standards

Develop/revise pretreatment standards

Investigate single pollution incidents (fish kills, oil spills)

Develop/assess/revise point source control strategies

Develop/assess/revise nonpoint source control strategies

Allocate resources

Report indices, trends, etc., to the public

Support enforcement actions

Develop/revise waste load allocations

conditions in selected streams and rivers in northeastern Illinois. Since organic pollutants and nutrients are considered the most general and widespread water quality problems in the region, the sampling and analysis program is designed to provide information necessary to simulate these parameters.

The stated objective for a land use runoff study is to determine nonpoint source pollution loading functions for homogeneous land uses. Transferability of data is required, since these loading functions will then be applied to other areas throughout the region.

The stated objective for a lake study is to determine, in terms of quantity and quality, the pollutional load from nonpoint sources that enters Lake Michigan during storm events. Note that this objective does not suggest that a complete survey of Lake Michigan be undertaken (a task of great magnitude) but, rather, seeks to determine what is going into the lake.

The three foregoing statements of objective were selected to illustrate that being specific and concise can go together (and should). As a final example, the following eight objectives are stated for an urban nonpoint source monitoring network:

- Collect basin rainfall and runoff data for 14 Philadelphia area drainage basins.

- Calibrate the USGS Dawdy parametric rainfall-runoff model using 3 to 5 years of data.

- Using long-term Weather Service rainfall records as input to the calibrated model, develop flood frequency duration curves for 14 urban drainage basins.

- Measure physical basin characteristics of the 14 urban drainage basins.

- Relate physical basin characteristics to optimized model parameters.

- Using developed regression relationships between model and basin characteristics, develop flood-frequency duration curves for ungaged basins.

- Verify results with collected data on selected test basins.

- Collect average stream quality data for development of quality trends as related to type of development.

Once the objective statement has been clearly formulated, the survey design can begin, but not before.

D.1.3 Types of Monitoring Activities

There exist a number of types of monitoring activities that can be employed in meeting overall monitoring requirements. Their suitability and applicability will depend upon the purposes and objectives of the particular effort involved. Included are (1) reconnaissance surveys, (2) point source characterizations, (3) intensive surveys, (4) fixed station network monitoring networks, (5) ground water monitoring, and (6) biological monitoring. The last two types of monitoring activities are broken out separately only because they require skills, equipment, and techniques that are markedly different from those used in the first four. None of these should be considered as completely separate activities in actual practice. Comprehensive data interpretation will require that all monitoring data be considered together.

A brief description of these monitoring activities follows, with emphasis placed on typical objectives of each. By comparing them, the reader can see how they differ and how they may be combined to meet overall 208 monitoring objectives.

D.1.3.1 Reconnaissance Survey

A reconnaissance survey is a general or overall examination of a particular area. It is a visual or superficial qualitative (and sometimes quantitative) survey. Typical objectives of a reconnaissance survey include:

1. Getting the "lay of the land" in preparation for an intensive survey.
2. Identification of all waste sources in a particular catchment.
3. Identification of water uses in terms of types, locations, quantities, and frequencies.
4. Determination of general stream characteristics.
5. Obtaining information necessary for establishing the overall design of a fixed-station network.
6. Investigation of reported pollution incidents or spills.

D.1.3.2 Point Source Characterization

A point source characterization (or effluent monitoring) study is one conducted to determine the characteristics of an identifiable, discrete discharge (either continuous or intermittent) into a receiving body of water. Although several point sources are usually involved in a complete survry, the mechanics of execution are basically similar, and the same general considerations apply. It is also possible that more than one measurement site (i.e., sampling and flow determination) might be involved as, for example, in a treatment plant efficiency study. Mass loading discharges rather than simple parameter concentrations are usually sought. Some objectives are:

1. Determination of frequency, quantity, and strength of combined sewer overflows.
2. Characterization of storm sewer discharges.
3. Determination of treatment plant efficiency.
4. Verification of a permit application.
5. Infiltration/inflow determination at a given site.

6. Verification of self-monitoring data with regard to permit compliance.
7. Determination of pretreatment requirements or verification of compliance with pretreatment standards.
8. Verification of toxic substances sources.
9. Case preparation (as part of an enforcement action).

D.1.5.3 Intensive Survey

Intensive surveys are major elements in a monitoring program. The intensive survey: (1) bridges the gap between the data bases generated by effluent monitoring and fixed-station monitoring; (2) provides a definitive basis for understanding and describing receiving water quality and the mechanisms and processes that affect water quality; (3) provides the documentation required to explain the trends observed at fixed network stations; and (4) is a tool for determining [illegible] ultimate fate of pollutants in the water environment.

Some generalizations concerning the overall nature of intensive surveys and their planning and execution follow.

1. Repetitive measurements of water quality are made at each station (sources and receiving water). The stations will typically comprise a short, very dense, sampling network throughout the duration of the field effort.

2. The duration of an intensive survey is dictated by the objectives of the survey, with 3 to 14 days being typical for freshwater streams, lakes, and reservoirs. Surveys in tidal bodies are typically more complex and longer in duration as are nonpoint source surveys (e.g., for calibrating a stormwater management model).

3. The measurements taken during an intensive study vary. A study may be oriented towards one particular type of data (chemical, biological, sediment, etc.) or it may involve the collection of many types of data.

4. Continuous and intermittent point and nonpoint sources within the survey area are usually monitored during the study.

Some major objectives of intensive surveys are:

1. Determining quantitative cause-and-effect relationships of water quality for making load allocations, assessing the effectiveness of pollution control programs, or for developing alternative solutions to pollution problems.

2. Setting priorities for establishing or improving pollution controls.

3. Supporting and setting priorities for enforcement actions.

4. Identifying and quantifying nonpoint sources of pollution and assessing their impact on water quality.

5. Assessing the biological, chemical, physical, and trophic status of publicly-owned lakes and reservoirs.

6. Providing data for the classification or reclassification of stream segments as being either effluent limited or water quality limited.

7. Evaluating the locations and distribution of fixed monitoring stations.

8. Calibrating and verifying stormwater management models.

Such objectives should be considered mutually compatible. The incremental cost of expanding a single-purpose survey into a multipurpose survey should always be evaluated prior to conducting the survey.

D.1.3.4 Fixed Station Monitoring Networks

The fixed monitoring network is a system of fixed stations that are sampled in such a way that well-defined histories of the physical, chemical, and biological conditions of the water and sediments can be established. In general, other monitoring data will be needed to explain, in detail, the trends observed at the fixed stations. Thus, a high level of coordination between the fixed-station monitoring network and other monitoring activities is essential for developing a useful data base. The basic objectives of fixed monitoring networks are to provide data and information that, when taken in combination with other data, will:

1. Characterize and define trends in the physical, chemical, and biological condition of surface waters, including significant publicly-owned lakes and impounded waters;
2. Establish baselines of water quality;
3. Provide for a continuing assessment of water pollution control programs;
4. Identify and quantify new or existing water quality problems or problem areas;
5. Aid in the identification of stream segments as either effluent limited or water quality limited;
6. Act as a triggering mechanism for intensive surveys, enforcement proceedings, or other actions;

D.1.3.5 Ground Water Monitoring

Because of the increasing threat to the quality of ground water posed by some waste management practices and a general lack of comprehensive information on the origins, scope, and nature of existing ground water pollution problems, it is important that programs be established and maintained to monitor ground water quality. Some objectives of ground water monitoring are:

1. Obtaining data for the purpose of determining baseline conditions in ground water quality and quantity.

2. Providing data for the early detection of ground water pollution or contamination, particularly in areas of ground water use.

3. Identifying existing and potential ground water pollution sources and maintaining surveillance of these sources, in terms of their impact on ground water quality.

4. Providing a data base upon which management and policy decisions can be made concerning the surface and subsurface disposal of wastes and the management of ground water resources.

Ground water monitoring has been extensively treated in a recent series of USEPA reports (1-5) and will not be discussed further in this Appendix. It is only mentioned here to point up its importance to the 208 planning process.

D.1.3.6 Biological Monitoring

Aquatic organisms and communities act as natural pollution monitors. Some organisms tend to accumulate or magnify toxic substances, pesticides, radionuclides, and a variety of other pollutants. Organisms also can reflect the synergistic and antagonistic interactions of point and nonpoint source pollutants within the receiving water system. Some objectives of a biological monitoring program are to gather biological data in such a manner as to:

1. Determine suitability of the aquatic environment for supporting abundant, useful, and diverse communities of aquatic organisms.

2. Provide information adequate to detect, evaluate, and characterize changes in water quality through the study of biological productivity, diversity, and stability of aquatic systems.

3. Detect the presence and buildup of toxic and potentially hazardous substances in aquatic biota.

4. Provide information adequate to periodically update the eutrophic condition classification of freshwater lakes.

D.1.4 Coordination With Other Monitoring Programs

An attempt to put 208 monitoring somewhat in perspective is presented in Figure D-1, taken from the National Water Monitoring Panel (6). It is obvious that if each functional purpose is to be productive, the proper information must be provided by the monitoring program. It also should be clear that persons responsible for monitoring must maintain a frequent and substantive contact with those programs requiring information. Finally, there is abundant need for coordination among all aspects of a monitoring program.

The importance of this last statement regarding coordination among monitoring activities can be emphasized by considering the following. At the federal level, legislative authority for monitoring is contained in at least six Acts:

- The Federal Water Pollution Control Act
- The Safe Drinking Water Act
- The Refuse Act
- The Marine Protection, Research and Sanctuaries Act
- The Federal Insecticide, Fungicide, and Rodenticide Act
- The Solid Waste Disposal Act

When combined with State and local legislation, the legislative mandates form an almost staggering dimension. The activities responsible for monitoring implementation form an equally large dimension. At the federal level alone,

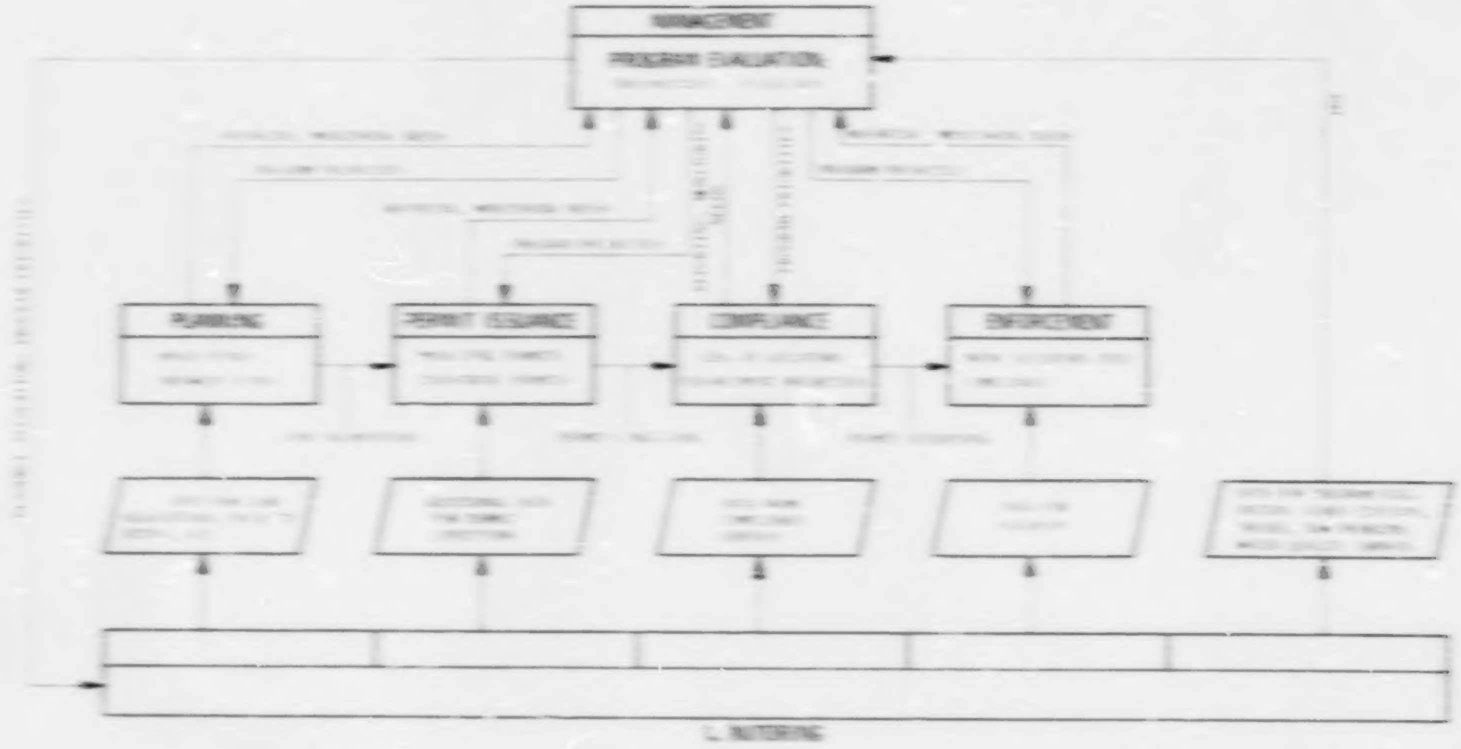


FIGURE II-1
MONITORING IN PERSPECTIVE

they include the U.S. Environmental Protection Agency; the U.S. Geological Survey; the U.S. Department of Agriculture; the Bureau of Reclamation; the Department of Defense, including the Army Corps of Engineers and the Naval Facilities Engineering Command; the Bureau of Mines; the National Aeronautics and Space Administration; the Occupational Safety and Health Administration; the Food and Drug Administration; the Energy Research and Development Administration; and others, not to mention special purpose monitoring efforts conducted by Federal activities such as the National Science Foundation, the Council on Environmental Quality, the Office of Manpower and Budget, the Office of Technology Assessment, and so on. These efforts must be combined with those of the states, designated agencies, and all pollutant dischargers operating under effluent permits. Typically, monitoring efforts are far from centralized. For example, in the USEPA alone, monitoring responsibilities - encompassing both the collection and use of information - are found in 16 Headquarters offices under 5 assistant administrators. Similarly, USEPA field responsibilities are dispersed among the 10 regional offices and 13 research laboratories.

D.1.5 Available Data Sources

The prudent use of resources dictates that the maximum use practicable be made of existing data. For 208 planning, these can be grouped into three categories: meteorological, geographical, and water quality. Available data sources for each category will be discussed in turn. One caveat more or less applicable to each must be mentioned, however. All prior data may not be of acceptable quality (i.e., truthfulness, suitability, accuracy). Where at all possible, attempt to determine the original source and some indication of the "goodness" of the data. For example, USGS stream gage records are annotated with a somewhat subjective indication of the quality of the record, e.g., poor, fair, good, etc. Unfortunately, this is the exception rather than the rule. Be especially chary of water quality records; attempt to determine how the samples were taken, whether or not they were handled properly, and how the analyses were run.

D.1.5.1 Meteorological Data

The best source of long-term rainfall data in the United States is the National Weather Service (NWS). Data can be obtained from the NWS either on tape files or through published daily and hourly summaries. Tapes can be obtained by contacting:

U.S. Department of Commerce
National Climatic Center
NOAA Environmental Data Service
Federal Building
Ashville, N.C. 28801

Telephone (704) 258-2850

Data are available on two record files: Deck 488-USWB HOURLY PRECIPITATION and Deck 345-WBAN SUMMARY OF DAY. Most first-order stations are covered. The period of record is usually from August 1949 to the current data with some gaps. Long-term 5-minute data are also available from the NWS for over 50 major U.S. cities, and can be generated for most cities having a NWS city or airport office.

One word of caution; be sure to determine if there is a high aerial variability of rainfall for the region in question. For example, the total rainfall measured at the NWS station at Philadelphia International Airport was 44.47 inches for 1975. The totals for individual gaged catchments within the city for the same period ranged from 40 to over 60 inches, with a city-wide average of 51.37 inches.

Other meteorological data available from NOAA include snowfall, temperature, wind, sunshine and sky cover, evaporation, and humidity. Local data sources and the possible existence of data from previous studies should also be investigated.

D.1.5.2 Geographical Data

In this context, the term geographical is used in its broadest meaning. Chief among this category are land use data, but other physical, cultural, and demographic data will also be desired (e.g., catchment slopes and terrain, soil types, sewer maps, population distributions, etc.). Sources of such data are described in detail in Appendix C of this Manual, but generally include:

- U.S. Census Bureau
- Metropolitan Sanitary Districts
- State and local planning agencies
- Office of the County Surveyor (or equivalent)
- U.S. Coast and Geodetic Survey
- U.S. Department of Housing and Urban Development
- USDA Soil Conservation Service
- Standard Metropolitan Statistical Area Data
- Previous basin (303e) or facilities (201) plans

D.1.5.3 Water Quality Data

The STORET system of the USEPA is the largest source of water quality data in the nation. The system is operated as a utility serving states, areawide agencies, and other organizations. Data are stored in the system by the data collecting organization for their own purposes as well as for sharing with others. The STORET system should be queried for existing data during the initial design phase of the 208 areawide monitoring effort. USEPA headquarters and regional offices may be contacted for assistance in the use of STORET.

Other existing water quality data are widespread, but the recent establishment of the National Water Data Exchange (NAWDEX) should considerably assist users in locating and acquiring needed data. Unlike STORET, NAWDEX is not a large depository of water data. Rather, its objective is to provide the user with sufficient information to define what data are available, where these data may be obtained, in what form the data are available, and some of the major characteristics of the data.

The U.S. Geological Survey has the lead-role responsibility for NAWDEX. In this capacity, it has established the NAWDEX Program Office at its National Center in Reston, Virginia. This office became active in November 1975 and provides the central management for NAWDEX. It also has the responsibility for coordinating all operational activities within the program. This includes serving as liaison between NAWDEX members and users of the system.

The service capabilities of NAWDEX will be supported by a nationwide network of Local Assistance Centers established in the offices of NAWDEX members to provide local and convenient access to NAWDEX and its services. This network will initially be established in late 1976 in the 46 district offices of the U.S. Geological Survey. These offices are located in 45 states and Puerto Rico. Most are equipped with computer terminals, thereby providing an extensive telecommunication network for access to the computerized directory and indexes being developed for the NAWDEX program. As the NAWDEX membership increases, additional centers will be added in large population areas and areas of high user interest to provide improved access to NAWDEX and its services.

The NAWDEX Program Office is currently developing a Water Data Sources Directory. This directory will identify organizations that collect water data, locations within these organizations from which water data may be obtained, the geographic areas in which water data are collected by these organizations, the types of water data collected, alternate sources for acquiring the organization's data, and the media in which the data are available. This directory is scheduled for release in 1977.

A computerized Master Water Data Index is also being prepared which is scheduled for nationwide use in November 1976. This index will identify individual sites for which water data are available, the locations of these sites, the organizations collecting the data, the hydrologic disciplines represented by the data, the periods of record, water data parameters, the frequency of measurement of the parameters, and the media in which the data are available. More than 350,000 water data sites are currently being indexed from information contributed by 19 federal agencies and more than 300 non-Federal agencies.

Through its Water Data Sources Directory, Master Water Data Index, and indexes and other reference sources made available by its participating members, NAWDEX assists its users in locating data of special interest. These data include water data in computerized and in both published and unpublished forms. The user is then referred to the organization(s) having the needed data. NAWDEX thus serves as a central point of contact for locating water data that may be held by several different organizations. Data search assistance may be obtained from the NAWDEX Program Office or from any of the Local Assistance Centers.

To expedite locating existing data, NAWDEX and STORET should be queried at the same time. In addition to referring the user to STORET, NAWDEX will provide information on other data sources for the area under consideration in many instances.

Requests for services or additional information related to NAWDEX and STORET may be directed to:

National Water Data Exchange
U.S. Geological Survey
421 National Center
Reston, VA 22092

Telephone (703) 860-6031

STORET (WH-553)
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Telephone (202) 426-7792

Local points of contact for the USEPA STORET system and state water quality agencies are given in Chapter 2 of this Manual (Tables 2-1 and 2-7). Selected federal sources for water quality information are given in Table D-3. A call to the Federal Information Center, (202) 755-8660, with its staff of trained information specialists, will assist the user in finding the appropriate contact within any of these federal agencies.

TABLE D-3
SELECTED FEDERAL SOURCES FOR WATER QUALITY INFORMATION

- Department of Agriculture
  - Forest Service
  - Soil Conservation Service
- Department of Commerce
  - National Oceanic and Atmospheric Administration
  - National Bureau of Standards
- Department of Defense
  - Army Corps of Engineers
  - Army Civil Engineering Research Laboratory
  - Navy Facilities Engineering Command
  - Air Force Civil Engineering Research Center
- Department of Health, Education, and Welfare
  - Public Health Service
- Department of Interior
  - Bureau of Reclamation
  - Bureau of Land Management
  - Bureau of Indian Affairs
  - Bureau of Mines
  - Bureau of Sport Fisheries and Wildlife
  - Bureau of Outdoor Recreation
  - Geological Survey
  - Office of Saline Water
  - Fish and Wildlife Service
  - Office of Water Resources Research
- Department of Transportation
  - Coast Guard
- Energy Research and Development Administration
- Environmental Protection Agency
- National Aeronautics and Space Administration
- Nuclear Regulatory Commission
- Water Resources Council
- Council on Environmental Quality

D.2 Measurement Site, Parameter, and Frequency Selection

D.2.1 Site Selection

The location of measurement sites is critical to obtaining good quality data and properly interpreting them. The following discussion covers overall site location guidance, site selection for waste load allocation surveys, catchment selection for stormwater model calibration and verification, and specific local site selection criteria.

D.2.1.1 Overall Site Location Guidance

For overall background and problem assessment the following locations are recommended for the chemical and physical sampling of the water column. Biological and sediment stations should also be established at these locations, as appropriate.

1. At critical locations in water quality limited areas. Stations should be located within areas that are known or suspected to be in violation of water quality standards, ideally at the site of the most pronounced water quality degradation. The data from these stations should gage the effectiveness of pollution control measures being required in these areas.

2. At the major outlets from and at the major or significant inputs to lakes, impoundments, estuaries, or coastal areas that are known to exhibit eutrophic characteristics. These stations should be located in such a way as to measure the inputs and outputs of nutrients and other pertinent substances into and from these water bodies. The information from these stations will be useful in determining cause/effect relationships and in indicating appropriate corrective measures.

3. At critical locations within eutrophic or potentially eutrophic lakes, impoundments, estuaries, or coastal areas. These

stations should be located in those areas displaying the most pronounced eutrophication or considered to have the highest potential for eutrophication. The information from these stations, when taken in combination with the pollution source data, can be used to establish cause/effect relationships and to identify problem areas.

4. At locations upstream and downstream of major population and/or industrial centers which have significant waste discharges into flowing surface waters. These stations should be located in such a way that the impact on water quality and the amounts of pollutants contributed can be measured. The information collected from these stations should gage the relative effectiveness of pollution control activities.

5. Upstream and downstream of representative land use areas and morphologic zones within the area. These stations should be located and sampled in such a manner as to compare the relative effects of different land use areas (e.g., cropland, mining area) and morphologic zones (e.g., piedmont, mountain) on water quality. A particular concern for these stations is the evaluation of nonpoint sources of pollution and the establishment of baselines of water quality in sparsely populated areas.

6. At the mouths of major or significant tributaries to mainstem streams, estuaries, or coastal areas. The data from these stations, taken in concert with permit monitoring data and intensive survey data, will determine the major sources of pollutants to the area's mainstem water bodies and coastal areas. By comparison with other tributary data, the relative magnitude of pollution sources can be evaluated and problem areas can be identified.

7. At representative sites in mainstem rivers, estuaries, coastal areas, lakes, and impoundments. These stations will provide data for the general characterization of the area's surface

waters and will provide baselines of water quality against which progress can be measured. The purpose of these stations is not to measure the most pronounced areas of pollution, but rather to determine the overall quality of the water. Biological monitoring will be a basic tool for assessing the overall water quality of an area.

B. In major water use areas, such as public water supply intakes, commercial fishing areas, and recreational areas. These stations serve a dual purpose: the first is public health protection and the second is for the overall characterization of water quality in the area. Determining the presence and accumulation of toxic substances and pathogenic bacteria and their sources are primary objectives of these stations.

Sediment sampling sites should be located in sink areas as determined by intensive surveys, reconnaissance surveys, and historical data. A major concern of sediment monitoring will be to assess the accumulation of toxic substances, and locations for sediment sampling should be chosen with this in mind. Sediment mechanics and the hydrological characteristics of the water body must be considered. Refer also to Chapter 4 of this Manual.

In general, biological monitoring stations should be established as follows:

1. At key locations in water bodies that are of critical value for sensitive uses such as domestic water supply, recreation, and propagation and maintenance of fish and wildlife.

2. In major impoundments near the mouths of major tributaries.

3. Near the mouths of major rivers where they enter an estuary.

4. At locations in major water bodies potentially subject to inputs of contaminants from areas of concentrated urban, industrial, or agricultural use.

5. At key locations in water bodies largely unaffected by man's activities.

For purposes of biological monitoring, a station will normally encompass areas, rather than points, within a reach of river or area of lake, reservoir, or estuary adequate to represent a variety of habitats typically present in the body of water being monitored. Unless there is a specific need to evaluate the effects of a physical structure, it is advisable to avoid areas that have been altered by a bridge, weir, within a discharge plume, etc. Thus, biological sampling stations may not always exactly coincide with water column or sediment stations.

To the extent possible, all monitoring stations should be located in such a manner as to aid cause/effect analyses. Some station requirements may be such that, with careful station siting, one particular station could meet the criteria of a number of types of stations. Caution should be exercised, however, to avoid compromising the worth of a station for the sake of false economy. In general, the quality of a monitoring program is not judged solely by the number of stations. A few critically located stations may be extremely valuable, while a large number of randomly selected stations may yield meaningless data. Resource constraints will limit the total number of stations. Figure D-2, taken from (6), shows some examples of station locations.

The stations shown on Figure D-2 are described as follows:

1. At a water supply intake; upstream station of a pair bracketing a municipal and industrial center.

2. At a critical location in a water quality limited segment; downstream station of a pair bracketing a municipal and industrial center; mouth of a significant input to a reservoir known to exhibit eutrophic characteristics.

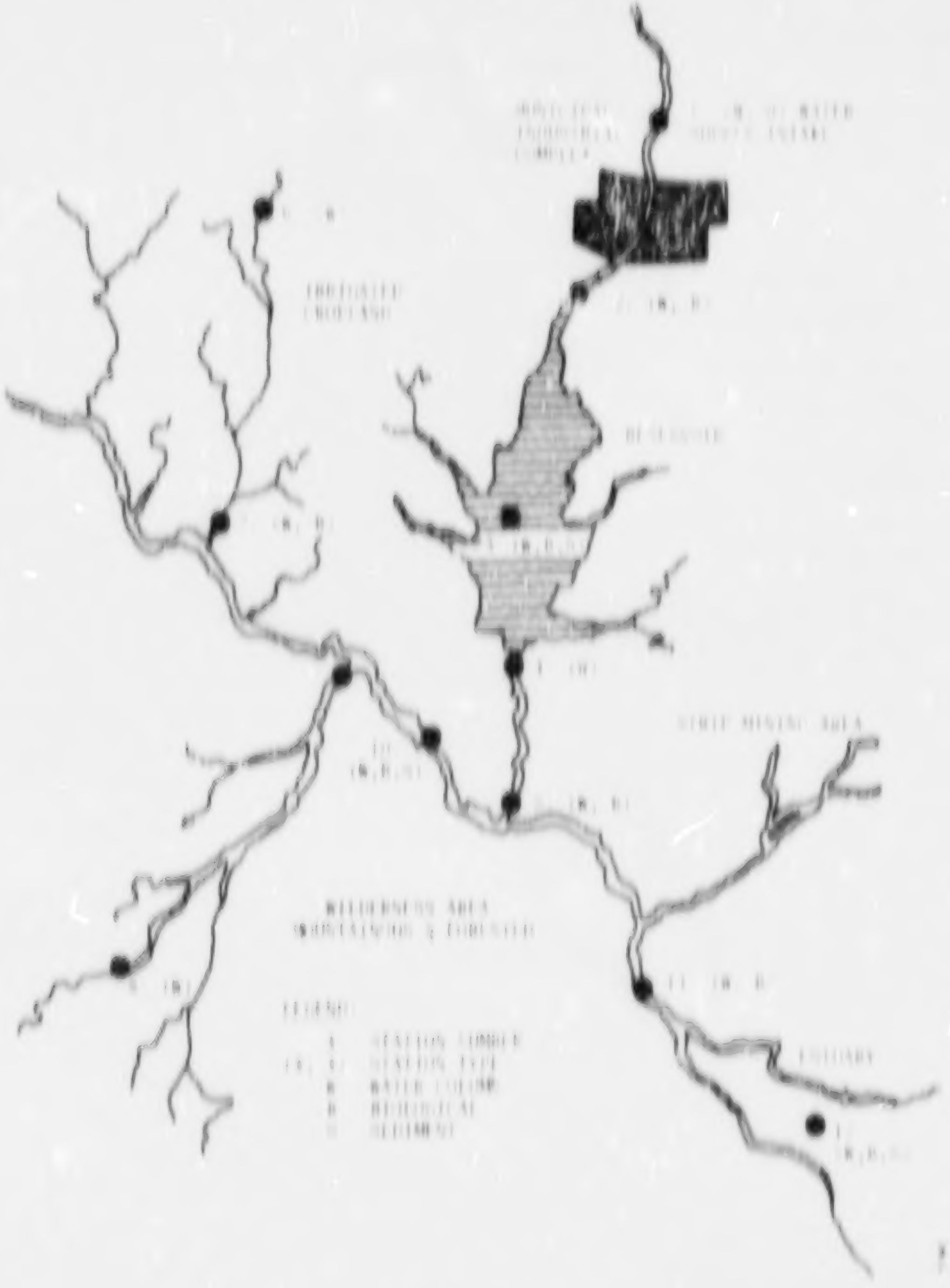


FIGURE D-2
STATION LOCATIONS

3. At a critical location in a reservoir known to exhibit eutrophic characteristics; in an area of recreation.

4. Upstream of a major land use area (strip mining); major outlet from a eutrophic reservoir.

5. Downstream of a land use area (strip mining); mouth of a significant tributary to mainstem river.

6. Upstream of a major land use area (irrigated cropland).

7. Downstream of a land use area (irrigated cropland); mouth of a significant tributary; representative site for other streams passing through same land use.

8. Upstream of a major land type area (wilderness).

9. Downstream of a major land type area (wilderness); mouth of significant tributary to mainstem river.

10. Representative site in mainstem river.

11. Representative site in mainstem river, mouth of major input to a potentially eutrophic estuary.

12. Representative site in estuary, recreational area, shellfish harvesting area.

D.2.1.2 Site Selection for Waste Load Allocation Surveys

Intensive surveys for waste load allocation will form an important part of a 208 agency's monitoring program. Since water quality problems don't manifest themselves on demand and we can't afford to wait around for the 10-year dry spell, the use of mathematical models for problem assessment will be required. These models will require monitoring data from intensive surveys for calibration and verification. By and large, at least two intensive surveys will be required for each waste load allocation study. The first, or preliminary, survey should be performed during slightly higher flow conditions than the second, or primary, survey which should be conducted when flow conditions are as low as possible.

For the case where only one outfall impacts upon the water quality of a stream, measurement sites should be located as follows:

A - directly upstream of the outfall.

B - effluent from the outfall.

C - mix point (i.e., where effluent is thoroughly mixed with stream flow).

D_i - intermediate points between the mix point and the DO sag point or a tributary, if one enters the stream ahead of the sag point. Spacing of 0.1 mile or less is usually warranted.

E - directly upstream of any tributaries.

F - tributary.

G_i - intermediate points between tributaries (if more than one) or between tributary and sag point.

H - sag point.

I_i - points downstream from the sag point. Measure at least every 0.1 mile until there is a definite recovery in the DO profile.

Where more than one outfall discharges into the stream, these sources must also be measured, and the above site locations altered accordingly.

The problem of determining the mix point deserves special mention. The common practice of locating the mix point either by visual inspection of the stream or by simply assuming that the stream is well mixed a certain distance downstream is simply inadequate. A more rigorous method must be used. One technique that has successfully been employed is to follow the concentration of chlorides downstream. The steps in this procedure are:

1. Measure chloride concentration upstream of the outfall.

2. Measure chloride concentration in the effluent.

3. Perform a mass balance calculation to determine the mixed chloride concentration.

4. Measure chloride concentrations at increasing distances downstream from the outfall.

5. Locate the mix point where the measured chloride concentration is equal to the calculated value.

B.2.1.3 Catchment Selection for Stormwater Model Calibration and Verification

Field data will be required for calibration and verification of stormwater models, with details dependent upon the actual model selected (see Appendix A). However, it must be emphasized at the outset that instrumentation of a large, multiuse drainage basin can only generate data for verification of urban planning models. Calibration of these models requires data from small catchments of uniform land use to provide information for adjusting model parameters for each individual land use. Since it will not be practicable to instrument all catchments within a planning area, the effectiveness of the planning models will depend to a large degree on the ability to estimate parameters for catchments that have no calibration data. This implies the selection of catchments that have a high potential for data transferability as "benchmark" stations and instrumenting them accordingly. Each instrumented catchment must therefore be viewed as a "sample" of the planning area's catchments. Selection of representative and (to the extent possible) uniform "samples" is necessary in order to arrive at a set of transferable model parameters that cover the variations among catchments for the entire planning area.

Catchment selection begins with an inventory of catchments in the planning area. Minimum characterization includes size; present and projected land use; drainage type (non-sewered, degrees of partial sewer service, fully sewered, and sewer types); physical catchment characteristics; and relationship to major streams, lakes, or estuaries within the area of interest. Catchments in urban areas are small and numerous, emphasizing the need for selecting a small, representative subset. The size will affect the relative importance of runoff flow and water quality constituent routing. Very small (e.g., less than 0.1 square mile) catchments should be avoided as their (typically) extremely rapid response times may make runoff characterization impossible. It is unlikely that the requirement for uniformity of land use will allow utilization of large (e.g., over 5 square miles) catchments in urban areas.

The extent of sewering will have a significant impact on catchment runoff, affecting routing, length of overland flow, and the relative importance of infiltration. In urban areas, the ratio of sewer length to drainage area typically falls between 8 and 18. The corresponding ratio for natural river and stream channels would be less than 2. The physical catchment characteristics such as percent imperviousness, ground slope, soil characteristics, and infiltration potential will obviously affect runoff and must be considered in selecting representative catchments for instrumentation.

The recommended procedure is to prepare a matrix inventory characterizing each catchment within the area of interest. These should then be categorized using land use as the factor, since parameters in currently available models are largely functions of land use. One should not feel constrained to use only the conventional single-family residential, multi-family residential, commercial, industrial, and open-space land use types. Use types reflecting the local conditions are more meaningful. For example, it may be desirable to distinguish between single-family residential areas near the center of a city and those in the suburbs; review of the catchment inventory may indicate a number of small suburban shopping centers and the desirability of a mixed residential/commercial category. Other locally important factors for determining land use types might be traffic volume, population density, age of development, family income, percent of streets with curb and gutter, type of industry, and so on. Although local conditions will determine the exact number of land use categories to be employed, fewer than five will probably not allow satisfactory data transfer and more than ten will increase field data collection costs beyond reason. See Appendix C of this Manual for further guidance.

The problem of site selection from among those catchments in each land use category now remains. Budgetary constraints will mandate selection of only one catchment for instrumentation in each land use category for the most part and, therefore, the "best" must be selected. Although random selection may be expedient, a more rigorous and comprehensive approach is usually desirable. On the other hand, a sophisticated multiple regression analysis with serial and/or factor differentiation of catchment variables is probably not warranted. The technique of weighted suitability ratings often employed in land use planning will be adequate in most instances. It has the advantage that the selection criteria can easily be illustrated on a single chart for relative catchment comparison. Although the procedure is necessarily subjective in the selection of factors, suitability values, and weights, so was the basic selection of land use types.

D.2.1.4 Specific Site Selection Criteria

Given an identified catchment, stream reach, or other general location where measurements are desired, there are some general criteria that can aid in selecting the specific measurement site. They include:

1. Maximum accessibility and safety. Manholes on busy streets should be avoided if possible; shallow depths with manhole steps in good condition are desirable. Sites with a history of surcharging or submergence by surface water, or both, should be avoided if possible.

2. Be sure that the site provides the information desired. Familiarity with the sewer system is necessary. Knowledge of the existence of inflow or outflow between the measurement point and point of data use is essential.

3. Make certain the site is far enough downstream from tributary inflow to ensure mixing of the tributary with the main stream.

4. Locate in a straight length of channel, at least six widths below bends.

5. Locate at a point of maximum turbulence, as found in sections of greater roughness and of probable higher velocities. Locate just downstream from a drop or hydraulic jump, if possible.

6. In all cases, consider the cost of installation, balancing cost against effectiveness in providing the data needed.

The success or failure of selected equipment or methods, with respect to accuracy and completeness of data collected as well as reasonableness of cost, depends very much on the care and effort exercised in selecting the site. A requirement with regard to flow measurement that appears to be obvious, but which is frequently not sufficiently considered, is that the site selected be located to give the desired flow measurement. Does flow at the site provide information actually needed to fulfill given needs? Sometimes influent flows, diversions, or storage upstream or downstream from the selected site would bias the data in a manner not understood without a thorough study of the proposed site. Such study would include reference to surface maps and to sewer maps and plans. Sometimes groundwater infiltration or unrecorded connections may exist. For these reasons, a thorough field investigation should be made before establishing a flow measurement site.

A basic consideration in site selection is the possible availability of measurements or records collected by others. At times, data being collected by the USGS, by the state, or by other public agencies can be used. There are locations where useful data, although not currently being collected, may have been collected in prior years. Additional data to supplement those earlier records may be more useful than new data collected at a different site.

Requirements that apply to all measurement sites are accessibility, personnel and equipment safety, and freedom from vandalism. If a car or other vehicle can be driven directly to the site at all times, the cost in time required for installation, operation, and maintenance of the equipment will be less, and it is possible that less expensive equipment can be selected. Consideration should be given to access during periods of adverse weather conditions and during periods of flood stage. Sites on bridges or at manholes where heavy traffic occurs should be avoided unless suitable protection for men and equipment is provided. If entry to sewers is required, the more shallow locations should be selected where possible. Manhole steps and other facilities for sewer access must be carefully inspected, and any needed repairs made. Possible danger from harmful gases, chemicals, or explosion should be investigated. With respect to sites at or near streams, historical flood marks should be determined and used for placement of access facilities and measurement equipment above flood level where this is possible. Areas of known frequent vandalism should be avoided.

In this last regard, the problem of vandalism can be serious and costly, both in terms of equipment damage and data loss. The selection of sites in open, rather than secluded, areas may help reduce vandalism as may illumination at night. Attempts to hide or camouflage equipment have been generally unsuccessful. Instrumentation should be sheltered to the extent possible, trading off the cost of protective facilities, the latitude afforded by the site, and the need for easy access. Occasionally, solid masonry or steel shelters surrounded by heavy fencing may be required for measurement sites, and these additional costs must be included in such instances. Finally, warning signs are generally unsuccessful; they may only encourage vandalism regardless of the type of threat -- high voltage, radiation hazard, fine, or imprisonment.

B.2.2 Parameter Selection

A review of the Parameter Handbook points out that the list of possible water quality parameters that might be of interest to the 208 planner is almost endless. Parameter selection must be based on the specific objectives of the study and a knowledge of general pollution source characteristics. For example, nonmunicipal effluent limitations guidelines for existing point sources, standards of performance for new sources, and pretreatment standards for new and existing sources discharging to publicly owned waste treatment facilities have been published for 28 point source categories (40 CFR 405-432). Effluent limitations establish the mass of specific pollutants that may be discharged per unit of production or raw material input. Limitations are established for a maximum production day and for the 30 day average. Table B-4 summarizes the effluent parameters included in each of the published effluent guidelines.

For publicly-owned treatment works in existence on July 1, 1977, or approved for a Federal construction grant prior to June 30, 1974, effluent limitations

TABLE D-4
EFFLUENT PARAMETERS BY INDUSTRIAL CATEGORIES

INDUSTRY CATEGORY
1. PULP, PAPER AND PAPERBOARD
2. BUILDERS PAPER AND BOARD
3. TIMBER PRODUCTS
4. SOAP AND DETERGENTS
5. DAIRY PRODUCTS
6. ORGANIC CHEMICALS
7. PETROLEUM REFINING
8. LEATHER TANNING AND FINISHING
9. CANNED AND PRESERVED FRUITS AND VEGETABLES
10. NONFERROUS METALS
11. GRAIN MILLS
12. SUGAR PROCESSING
13. FERTILIZERS
14. ASBESTOS
15. MEAT PRODUCTS
16. FEEDLOTS
17. GLASS
18. ELECTROPLATING
19. PHOSPHATE MANUFACTURING
20. FERROALLOYS
21. CEMENT MANUFACTURING
22. RUBBER PROCESSING
23. PLASTICS AND SYNTHETICS
24. INORGANIC CHEMICALS
25. IRON AND STEEL
26. TEXTILES
27. STEAM ELECTRIC GENERATING EQUIPMENT
28. SEAFOOD PROCESSING
TOTALS

are based upon an effluent standard of secondary treatment. Secondary treatment is defined in 40 CFR 133.102 and consists of:

Parameter	7-day Average	30-day Average
BOD_5	45 mg/ℓ	30 mg/ℓ
Suspended Solids	45 mg/ℓ	30 mg/ℓ
Fecal Coliform Bacteria (geometric mean)	400/100 mℓ	200/100 mℓ
Removal Efficiency		85 percent
pH	6.0 - 9.0	

The recommended procedure is to examine the sources and processes involved in the study area and, on the basis of need-to-know and reasonable expectation, select measurement parameters accordingly. Flow should always be included. Parameters should not be limited to those that are known to be a problem, but should also include those that can reasonably be expected to become a problem. The 208 monitoring program should identify new problems as well as track existing ones. The results of early analyses should be used to assess parameter coverage and assist in determining whether an increase or decrease is warranted. Resist the temptation to "look at the whole world." Analyses cost money, and wise resource management dictates that only parameters, the knowledge of which directly supports specific study objectives, should be included. Put in writing a justification for each parameter selected. Use the Parameter Handbook for guidance.

B.2.2.1 Parameters for Storm-Generated Discharges

Parameter selection will be facilitated by initially considering water quality characteristics in gross categories rather than as specific compounds or elements. As an example, the following treats the quality characteristics considered important for storm-generated discharges. See Wullschleger et al. (7) for elaboration.

D.2.2.1.1 Oxygen Demand

One of the most important quality characteristics in a receiving body of water is the dissolved oxygen concentration. The dissolved oxygen concentration has a direct bearing on the quality and natural balance of much of the aquatic biota. Dissolved oxygen concentration can also have an effect on the recreational and aesthetic uses of a body of water. Storm-generated discharges that contain organic and inorganic compounds that exert a demand for the oxygen dissolved in water can be considered pollutional discharges in the same sense as dry-weather municipal wastewaters.

Oxygen demand is exerted by (1) organic compounds that undergo biochemical oxidation as a result of microbial activity and (2) by the immediate demand exerted by the chemical oxidation of inorganic reduced compounds. However, storm-generated discharges have certain characteristics different from municipal sewage that affect not only the DO level in the receiving waters, but also the conventional tests used to measure oxygen demand. Since combined sewer overflows have a variety of sources other than just municipal sewage, the discharges may contain materials that cause special problems. During dry weather, when flow through a combined sewer system is low, solids settle out. At the start of a storm, the first flush of water through the system may have a high concentration of solids that affects the demand characteristics of the waste. It has been found that the fraction of BOD in the particulate form can range from 69 to 87 percent, which is considerably higher than the 30 to 50 percent present in most municipal wastewaters. Also, combined sewer overflows from industrial areas and urban runoff may contain oils, toxic materials and chemicals which are foreign to the natural environment and interfere with traditional oxygen demand tests. Finally, storm-generated discharges contain a large amount of natural materials such as silt, vegetation, wood, and other materials such as plastic that may not exert an immediate demand but will eventually use the oxygen required for decomposition. These characteristics cause these discharges to be different from that waste normally encountered in sanitary analyses.

There are numerous tests available for use as potential oxygen demand indicators, including BOD_5, BOD_{20}, BOD_x, ACOD, COD, TOC, and TOD. The desired test should have a well established, standardized test procedure and provide a measurement of the total oxygen demand on the environment. No single analytical test can meet both of these criteria. Therefore, two parameters are recommended to indicate oxygen demand of storm-generated discharges, TOD and BOD_5. TOD reflects the long-term demand, allowing correct determination of discharge effects, and lacks the serious interference problems of other tests, notably COD. BOD_5 is recommended, despite its numerous disadvantages, because of its widespread and historical use. Also, because of toxicity effects on the BOD_5 test, comparison of BOD_5 and TOD results can yield information about the degree of toxicity and its possible effect on the natural environment.

II.2.2.1.2 Particulate Concentration

The solid matter present in storm-generated discharges can be divided into two major categories; namely, particulate solids and dissolved solids. Particulate solids are important in combined sewer overflows and storm runoff applications because they usually represent a large fraction of the total solids. Also, these solids are generally removed from the flow by physical treatment processes such as sedimentation, screening, flotation, and filtration--the type of processes most commonly used for storm-generated discharges. It is, in fact, the relatively high concentration of particulate solids in these flows which makes such processes attractive.

The recommended parameter for indicating particulate concentration in storm-generated discharges is nonfilterable residue (suspended solids). The analysis is routine and not as time consuming and cumbersome as some of the other particulate tests and, with a few additional steps, both the volatile and fixed portions can be determined, yielding another useful piece of information in most instances. Where settleable residue is desired, the gravimetric method is recommended, not the Imhoff cone. Turbidity measurements provide little comparable data about particulate matter or concentration and are not recommended for this purpose.

D.2.2.1.3 Pathogenic Microorganism Potential

Any discharge that includes waters which have come into contact with excrement from warm-blooded animals of any type should be considered as having the potential for conveying pathogenic bacteria, viruses, protozoa, and other contagions. It is extremely difficult, if not logistically impossible, to monitor these discharges for the many pathogens themselves. This problem was recognized in the water supply field many years ago and has led to the almost universal usage of the coliform group of bacteria as the indicator or measure of the sanitary quality of water. The coliforms themselves are not necessarily pathogenic, but their presence should infer the possible presence of pathogens. However, for a number of reasons the coliform group is not necessarily the most sensitive indicator as far as storm-generated discharges are concerned.

The recommended indicator parameters are fecal coliform and fecal streptococcus. Furthermore, it is recommended that the membrane filter (MF) technique be used rather than the multiple tube fermentation procedure where results are expressed as the most probable number (MPN) statistic.

D.2.2.1.4 Eutrophic Potential

In addition to sunlight and carbon dioxide, aquatic plants require nutrients and trace salts. The principal nutrients are compounds which contain the elements phosphorus, nitrogen, and potassium. The proliferation of aquatic plants in most water bodies is undesirable. The term "eutrophic" refers to a condition in a water body where copious plant growth has resulted in an undesirable or unsightly situation of accelerated lake deterioration. Although eutrophication is a natural process, it can be accelerated by man's activities.

Nitrogen and phosphorus are measures of the eutrophic potential of storm-generated discharges. It is recommended that two nitrogen analyses be conducted, nitrate plus nitrite (run by reducing nitrate to nitrite and measuring the latter) and Kjeldahl. Of the 11 different phosphorus fractions, total phosphorus is the recommended parameter.

D.2.a.1.5 Toxic and Related Substances

A large number of compounds of varying toxicity and concentration are likely to be found in combined sewer overflows and storm runoff. However, the toxicants of major concern can be divided into the general categories of heavy metals, pesticides, and herbicides.

When studying the quality of storm flows, it is recommended that a composite sample of the flow be analyzed for lead, zinc, copper, chromium, mercury, cadmium, arsenic, nickel, and tin four times a year (seasonally). Based upon the results of these tests, a decision can be made as to how often certain heavy metals will have to be analyzed thereafter. It is expected that lead, zinc, copper, and chromium may be measured routinely. In certain combined sewer areas serving known industries, or in certain storm sewer discharges from areas of heavy vehicular traffic, it may be necessary to do more frequent analysis.

Because of the wide variability of pesticides in use, the periodic nature of their application depending upon season and nature of the drainage area, and the complexity of the laboratory analyses, no pesticides or associated compounds are recommended for routine analysis. However, it is recommended that, when evaluating the quality of a storm-generated discharge, a study of the drainage area should be made to determine the likelihood of pesticide application (and the type) and if it is probable that the storm flow may contain pesticides. At least one discharge should be analyzed to see if that pesticide is present. Depending upon this result, a decision can be made as to whether more analyses are needed.

B.2.2.1.6 Other Parameters

There are a host of other parameters that can be used to characterize storm-generated discharges. In the absence of site specific concerns, however, only pH is recommended for routine measurement.

B.2.2.2 Parameters for a National Water Quality Monitoring Program

As a further aid in parameter selection, the proposed minimum parameter list for a national water quality monitoring program will be discussed. Temperature, pH, and dissolved oxygen are included because they are the primary constituents in most chemical reactions that occur within the waterbody. They are also the essential factors that govern whether the ecosystem will maintain aquatic life. A conductivity measurement is included to determine the degree to which dissolved solids contribute to the water quality. This is a most reliable measurement and can be done on site. Salinity is measured in estuaries and bays.

Fecal coliform is included because it is, at present, the most reliable test for indicating the possible presence of pathogenic microorganisms in the system. Trace metals were limited to those that are of high priority and are toxic. Since the concern of the program is to measure the total load, total metals instead of dissolved forms are measured.

In order to determine the extent of total nutrient contribution, total phosphorus, total Kjeldahl nitrogen, and nitrite and nitrate are measured. Since the basic concern of the program is the total nutrient load, total phosphorus is measured instead of the other various forms of phosphorus.

This is also more economically sound. In determining the contribution of nitrogen to the system, the concern of the program is also to arrive at some understanding of the stage of nitrification within the system. Therefore, total Kjeldahl nitrogen is included as a measurement of organic nitrogen and ammonia, and nitrate and nitrite are included to determine the extent of oxidized nitrogen.

A total suspended solids measurement is included to measure the contribution of solid material to the system and to give some indication of water clarity and the probability of chemical adsorption.

A chemical oxygen demand (COD) measurement is included to get an indication of the oxygen demand placed on the system. Chemical oxygen demand was chosen over biochemical oxygen demand (BOD) and total organic carbon (TOC) because it is more reliable than BOD, does not involve problems with holding time and sample transport as do BOD samples, and does not require the sophisticated equipment required of a TOC measurement. COD is not measured in lakes and impoundments because it is usually found only in such low concentrations that it renders the measurement meaningless. TOC is measured in estuaries because the COD measurement does not yield satisfactory results in salt water due to chloride interference.

The trace organics included in the program were chosen because they appear most frequently on several USEPA priority lists relating to toxic substances; for example, measurements required for the permit program, measurements required for the drinking water program, the Section 307(a) list, and several listings proposed by the Office of Toxic Substances.

The effects of contaminants on aquatic organisms are complex. Synergistic chemical/physical reactions, biomagnification, and other natural events cannot be easily quantified. For these reasons and for the purposes of the program, the best approach to determine the presence and potential health threat of toxic substances in the ecosystem appears to be the chemical analysis of fish and shellfish tissue. This has, therefore, been included in the monitoring program.

D.2.2.3 Parameters for Waste Load Allocations

As an example of possible parameter coverage for waste load allocation surveys, Tables D-5 and D-6 indicate minimum parameters for the preliminary and primary intensive surveys discussed in Section D.2.1.2. The measurement locations indicated in the tables are those described in Section D.2.1.2. In addition to the indicated parameters, it will usually be desirable to perform a metals and pesticide scan on at least one sample from the preliminary survey and, based on the results, consider additional parameters for the primary low flow survey.

D.2.3 Measurement Frequency Selection

Monitoring frequencies are established by the variations of the system (sources and receiving water) and the nature of the pollutants (conservative and nonconservative). Frequencies selected should be adequate to account for variations in the flows and quality of pollution sources, the variations in stream flow, and tidal action. This establishes a spectrum ranging from a periodic grab sample (suitable for the rare steady-state condition) to continuous collection over a suitable time period.

D.2.3.1 Frequency for Background and Trend Data

Background and trend data must be representative of the variations in water quality and changes in pollution occurring over the course of a year, and the measurement frequency must be less than the shortest anticipated frequency of pollutant variation. To aid in such sampling frequency determination, Tables D-7, D-8, and D-9 present the proposed sampling frequencies for the national water quality monitoring program for rivers and streams, lakes and impoundments, and estuaries and bays.

The sampling frequencies given in the foregoing represent the bare minimum and, depending upon the anticipated variability, considerations should be given to utilizing more frequent intervals. If at all possible, new stations should be sampled on a weekly or biweekly basis for the first 6 months to

TABLE D-5
PARAMETERS FOR PRELIMINARY SURVEY

Location	DO	Temp	Distance Downstream	Travel Time	Flow Measurement	BOD_{20}	BOD_{20} Inh	Nitrogen Compounds
A	X	X			X		X	X
B	X	X			X	X	X	X
C	X	X	X	X	X			
D_1	X	X	X	X*				
E	X	X	X		X			
F	X	X	X		X			
G_1	X	X	X	X*				
H	X	X	X	X				
I_1	X	X	X	X*	X*			

* Measurements need be taken at only one of the multiple locations designated by each of D_1, G_1, or I_1.

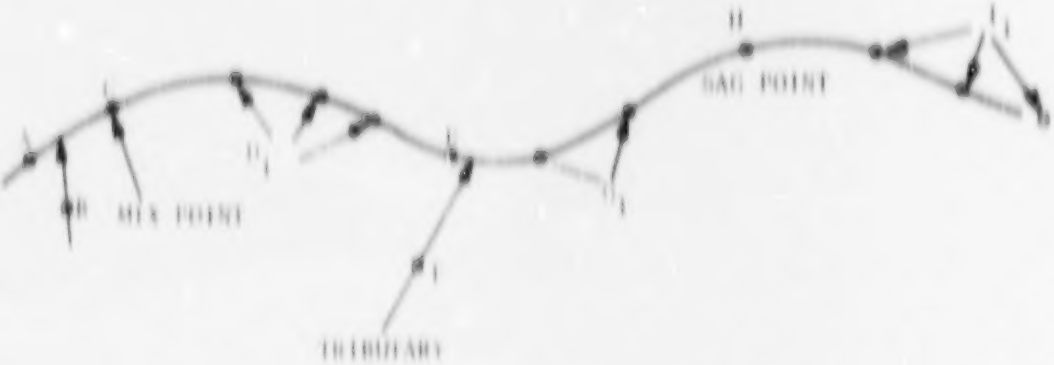


TABLE 6
PARAMETERS FOR PRIMARY SURVEY

Location	DO	pH	Temp	Distance Downstream	Travel Time	Flow Measurement	Continuous DO	Nitrogen Compounds	BOD_5	BOD_5 Inh	BOD_{20} Inh
A	x	x	x			x		x			x
B	x	x	x			x		x	x	x	x
C	x	x	x	x	x	x	x	x			x
D_1	x	x	x	x	x			x		x	
E	x	x	x	x	x	x				x	
F	x	x	x	x		x		x			x
G_1	x	x	x	x	x			x		x	
H	x	x	x	x	x		x	x			x
I_1	x	x	x	x	x	x*		x		x	

* Measurements need be taken at only one of the multiple locations designated by I_1.

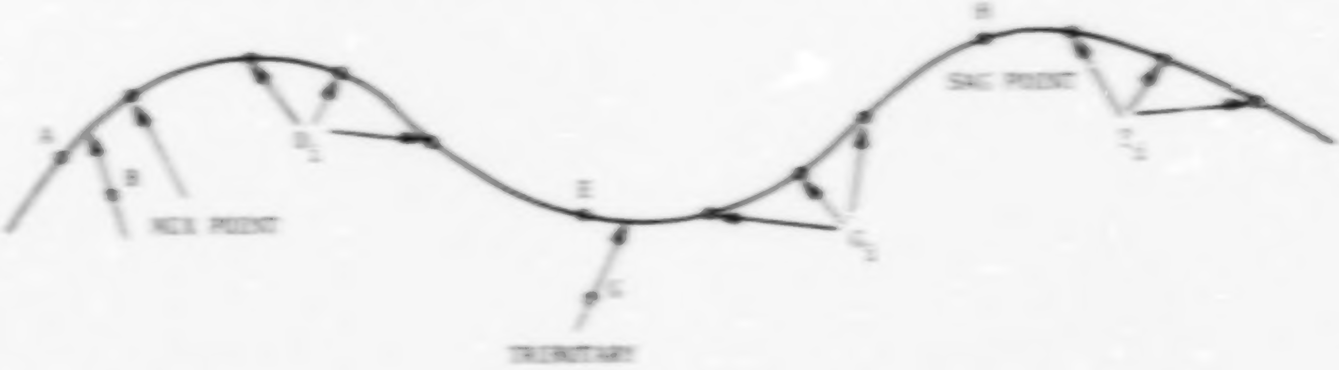


TABLE D-7
PARAMETER LIST AND SAMPLING FREQUENCY
FOR THE NATIONAL MONITORING PROGRAM

Rivers and Streams	
Parameter (Units) (STORET Parameter Code)	Sampling Frequency
Temperature (C°) (00010)	Monthly
Dissolved oxygen (mg/l) (00300)	Monthly
pH (Standard Units) (00400)	Monthly
Conductivity (umhos/cm @ 25°C) (00095)	Monthly
Fecal Coliform (No./100ml) (31616)	Monthly
Total Kjeldahl nitrogen (mg/l) (00625)	Monthly
Nitrate + nitrite (mg/l) (00630)	Monthly
Total phosphorus (mg/l) (00665)	Monthly
Chemical oxygen demand (mg/l) (00335)	Monthly
Total suspended solids (mg/l) (00530)	Monthly
Representative fish/shellfish tissue analysis (see Table D-8)	Annually
Flow (CFS) (00060)	Monthly

TABLE D-7
PARAMETER LIST AND SAMPLING FREQUENCY FOR THE NATIONAL MONITORING PROGRAM (Cont'd)

Lakes and Impoundments, Including the Great Lakes	
Parameter (Units) (STORET Parameter Code)	Sampling Frequency
pH (Standard Units) (00400)	Seasonally
Temperature (°C) (00010)	Seasonally
Dissolved oxygen (mg/l) (00300)	Seasonally
Conductivity (UMHOS/cm @ 25°C) (00095)	Seasonally
Fecal Coliform (No./100ml) (31616)	Seasonally
Total phosphorus (mg/l) (00665)	Seasonally
Total Kjeldahl nitrogen (mg/l) (00625)	Seasonally
Nitrate + nitrite (mg/l) (00630)	Seasonally
Total suspended solids (mg/l) (00530)	Seasonally
Representative fish/shellfish tissue analysis (see Table D-8)	Annually
Transparency Secchi Disk (Meters) (00078)	Monthly

TABLE B-7
PARAMETER LIST AND SAMPLING FREQUENCY
FOR THE NATIONAL MONITORING
PROGRAM (Cont'd)

Estuaries and Bays	
Parameter (Units) (STORET Parameter Code)	Sampling Frequency
Temperature (°C) (00010)	Monthly
Dissolved oxygen (mg/l) (00300)	Monthly
Total organic carbon (mg/l) (00680)	Monthly
pH (Standard Units) (00400)	Monthly
Salinity (°/oo) (00480)	Monthly
Fecal Coliform (No/100ml) (31616)	Monthly
Transparency Secchi Disk (Meters) (00078)	Monthly
Total Kjeldahl nitrogen (mg/l) (00625)	Monthly
Total phosphorus (mg/l) (00665)	Monthly
Nitrate + nitrite (mg/l) (00630)	Monthly
Total suspended solids (mg/l) (00530)	Monthly
Representative shellfish tissue analysis (see Table B-8)	Annually

TABLE D-8
TRACE ORGANICS AND METALS ANALYSES FOR WATER COLUMN[1]

Parameter (STORET), (µg/l)

PCBs (39516)
Aldrin (39330)
Dieldrin (39380)
o,p-DDE (39327)
p,p'-DDE (39320)
o,p-DDD (39315)
p,p'-DDD (39310)
o,p-DDT (39305)
p,p'-DDT (39300)
Chlordane
  cis isomer (39062)
  trans isomer (39065)
  cis nonachlor (39068)
  trans nonachlor (39071)

Endrin (39390)
Methoxychlor (39480)
Hexachlorobenzene (39700)
Pentachlorophenol (39032)
Hexachlorocyclohexane
  α-BHC (39337)
  γ-BHC (39810)
Arsenic (01002)
Cadmium (01027)
Chromium (01042)
Copper (01034)
Mercury (71900)
Lead (01051)

(1) For water column analysis when applicable (24).

TABLE D-9
TRACE ORGANICS AND METALS ANALYSES FOR FISH/SHELLFISH TISSUE AND SEDIMENT

Parameter (STORET:tissue, STORET:sediment), (µg/g tissue, µg/kg sediment)

PCBs (39520,39519)
Aldrin (39334, 39333)
Dieldrin (39387, 39383)
o,p-DDE (39329, 39328)
p,p'-DDE (39322, 39321)
o,p-DDD (39325, 39316)
p,p'-DDD (39312, 39311)
o,p-DDT (39318, 39306)
p,p'-DDT (39302, 39301)
Chlordane
  cis isomer (39063, 39064)
  trans isomer (39066, 39067)
  cis nonachlor (39069, 39070)
  trans nonachlor (39072, 39073)

Endrin (39397, 39393)
Methoxychlor (39482, 39481)
Hexachlorobenzene (39703, 39701)
Pentachlorophenol (39060, 39061)
Hexachlorocyclohexane
  α-BHC (39074, 39076)
  γ-BHC (39075, 39811)
Arsenic (01004, 01003)
Cadmium (71940, 01028)
Chromium (71939, 01029)
Copper (71937, 01030)
Mercury (71930, 71921)
Lead (71936, 01052)

1 year of operation or until the data indicate that less frequent sampling is warranted.

Fish samples should be collected annually in the fall, since contaminant concentrations are at their maximum at this time of year. Only fish samples that will be most representative of the water quality in the area of interest should be collected for tissue analysis. Migratory species should be discounted. Two replicate whole fish composite samples of a representative bottom feeder and one whole fish composite sample of a predator species should be collected at each station. Commercially or recreationally important species should be collected wherever possible. Each composite should include at least five fish, each of approximately the same size. Because of their sedentary existence and great water-filtering capabilities, shellfish are excellent concentrators of contaminants. Therefore, wherever possible, shellfish samples should be collected and analyzed, especially in estuarine environments.

Where incidents of fish kill occur, the appropriate information should be recorded. This should include the date of occurrence (or period if it persists), the location or affected area, the species affected, estimates of the magnitude of the kill (i.e., number of fish), and any other information that would be useful. The frequency and magnitude of such events should decrease as a result of implementing the areawide plans, and this can be a dramatic way of indicating progress.

II.2.3.2 Frequency for Waste Load Allocation Surveys

Samples could be taken at any convenient time if stream conditions did not vary. The necessary number of samples would be only that dictated by the desired degree of precision of the results, taking into account the precision of the laboratory analytical methods. In theory, the times of collection and numbers of samples are dictated by the need to ensure both an acceptable measure of the variations in stream conditions and an acceptable precision of laboratory analysis. In practice, these considerations are tempered by inescapable limitations of budget, personnel, and facilities, and frequently by the amount of time available.

There is no fixed number of samples that will yield results within selected limits of precision in all situations. The number of samples needed for any point on a stream varies with the variability in water quality at that point. A preliminary estimate of the variability can be calculated after a limited number of analytical results has been obtained. A preliminary prediction of the number of samples needed to ensure final results within selected confidence limits can be based on the preliminary estimate of variability. The prediction can be refined as the number of analytical results is increased until the point is reached at which a firm prediction of the number of samples required becomes possible. Data from a previous study under comparable conditions may be used to determine variability and predict the number of samples required.

In the absence of better information, daily grab samples should be taken from each stream measurement site over at least a 14-day period. Furthermore, the time of sampling at each site should be varied as much as possible to indicate any diurnal variations. Try to collect at least one set of samples at night to indicate photosynthetic effects. Review the analytical results from the early samples, and adjust the frequency accordingly.

For continuous point source discharges, the sampling frequency will also be dependent upon anticipated pollutant variability. If knowledge about the time-varying characteristics of the discharge is required, collect a sequential discrete sample series. Hourly time steps will be adequate for most continuous discharges, but in some instances either shorter time periods or flowmeter pacing will be required. If only average daily loadings are required, twenty-four-hour, flow proportional composite samples represent the best approach. These should be taken over a minimum of five consecutive days, and longer if variability indicates.

B.2.3.3 Frequency for Storm Generated Discharges

For intermittent storm related discharges, measurement frequencies must be quite short, especially for model calibration and verification where knowledge of temporal variations is very important. The measurement interval required is related to catchment size, shape, slope, and percent imperviousness. During sampling of the first few storms in a catchment, it is prudent to estimate sampling intervals on the short side. They can be increased later if the data warrant. Model input frequency requirements must also be considered. Suggested minimum measurement intervals are given in Table D-10. The first sample should be collected as close to the beginning of the storm-generated runoff as possible. This can be accomplished by triggering an automatic sampler at a predetermined indication of stage or rate of rise. Subsequent samples can be paced by timer settings or a flowmeter with flow increments selected so that the rising limb is well characterized. It may not be necessary to analyze all samples on the falling limb. Early data analysis will indicate if some can be eliminated or composited and still allow adequate discharge characterization.

D.3 Flow Measurement Considerations, Equipment, and Procedures

Although flow can be thought of as simply another parameter, it is so often neglected that it should properly be considered as an essential component of a monitoring program. Flow measurements are absolutely necessary for mass discharge calculations, stream and runoff studies, and model calibration and verification.

D.3.1 General Considerations

Concentrations of natural constituents, such as alkalinity, hardness, and minerals, generally vary inversely with stream flows. Total loads, or quantities, of natural constituents carried by a stream, on the other hand, increase as flow increases. The increasing water carried by the stream more than balances the decreasing concentration to yield a greater load in terms of a unit of total quantity, such as pounds per day. Other factors come into play with unstable constituents. Time-of-water travel increases as flow decreases, and this serves to accomplish natural purification in shorter distances. Higher densities of bacteria, for example, occur just below the

TABLE D-10
MAXIMUM MEASUREMENT INTERVALS

Catchment Size	Variable	Desirable Maximum Measurement Interval (min)	
		Highly Impervious Catchment	Highly Pervious Catchment
50 acres	Rainfall	2	3
	Flow	2	3
	Water Quality	3	4
100 acres	Rainfall	3	5
	Flow	3	5
	Water Quality	4	7
600 acres	Rainfall	5	12
	Flow	5	12
	Water Quality	7	20
3000 acres	Rainfall	12	20
	Flow	12	20
	Water Quality	15	30

point of discharge at lower flows, but they die off in shorter distances because of the longer time of travel. Likewise, BODs are higher near the point of discharge but stabilize in shorter distances at low discharges.

The natural flow of uncontrolled streams usually varies over a wide range. Stream flows follow precipitation patterns except in the colder areas of the country, where precipitation falls as snow in winter and much of the surface water is frozen. There can be wide differences in stream flow throughout the year and in the annual flow cycle from year to year. Flow in most areas tends to be high in late winter and to taper off to minimum quantities in the fall. High flows usually occur in colder areas when relatively warm spring rains melt the winter accumulation of ice and snow. However, the natural cycle may be altered to a considerable extent in streams controlled by impoundments. Thus, stream flows must be considered in selecting periods for stream study because of the considerable variations in water quality that accompany changes in flow. The objectives of the study are important in this selection, as they are in other decisions.

In manmade conduits, the effects of flow variation are probably greatest in storm sewers. Although storm sewers are basically designed to carry storm runoff, during periods of no rainfall they often carry a small but significant flow (dry weather flow). This may be flow from ground water, or "base flow," which gains access to the sewer from unpaved stream courses. Much of the dry weather flow in storm sewers is composed of domestic sewage or industrial wastes or both. Where ordinances concerning connections to sewers are lax or are not rigidly enforced, unauthorized connections to storm sewers will appear. In some cases, the runoff from septic tanks is carried to them. Connections for the discharge of swimming pools, foundation drains, sump pumps, cooling water, and pretreated industrial process water to storm sewers are permitted in many municipalities and contribute to flow during periods of no rainfall. In some areas, sewers classed as storm sewers are, in fact, sanitary or industrial waste sewers due to the unauthorized or inappropriate connections made to them. This may become so aggravated that a continuous flow of sanitary or industrial wastes, or both, discharges into the receiving stream. Furthermore, this "dry-weather" portion of storm sewer flow may vary significantly with time.

Storm runoff is the excess rainfall which runs off the ground surface after losses resulting from infiltration to ground water, evaporation, transpiration by vegetation, and ponding occur. In general, storm runoff is intermittent in accordance with the rainfall pattern for the area. It is also highly variable from storm to storm and during a particular storm. The time-discharge relationship, or hydrograph, of a typical storm, with its synchronous time-precipitation relationship, or hyetograph, is illustrated in Figure D-1. The meanings of various parameters given in the figure are:

R_p = Rainfall retained on the permeable portion of the drainage basin, and not available for runoff.

P_e = Precipitation in excess of that infiltrated into the ground, plus that retained on the surface. (Equals the volume of flood runoff.)

F_{av} = Average infiltration of the ground during the storm.

T_r = Period of rise from the beginning of storm runoff to peak of the hydrograph.

T_p = Time from center of gravity of rainfall excess to the hydrograph peak (lag time).

b_1, b_2 = Baseline separating groundwater discharge from surface runoff.

The total volume of runoff for a particular storm is represented by the areas between the baseline and the hydrograph.

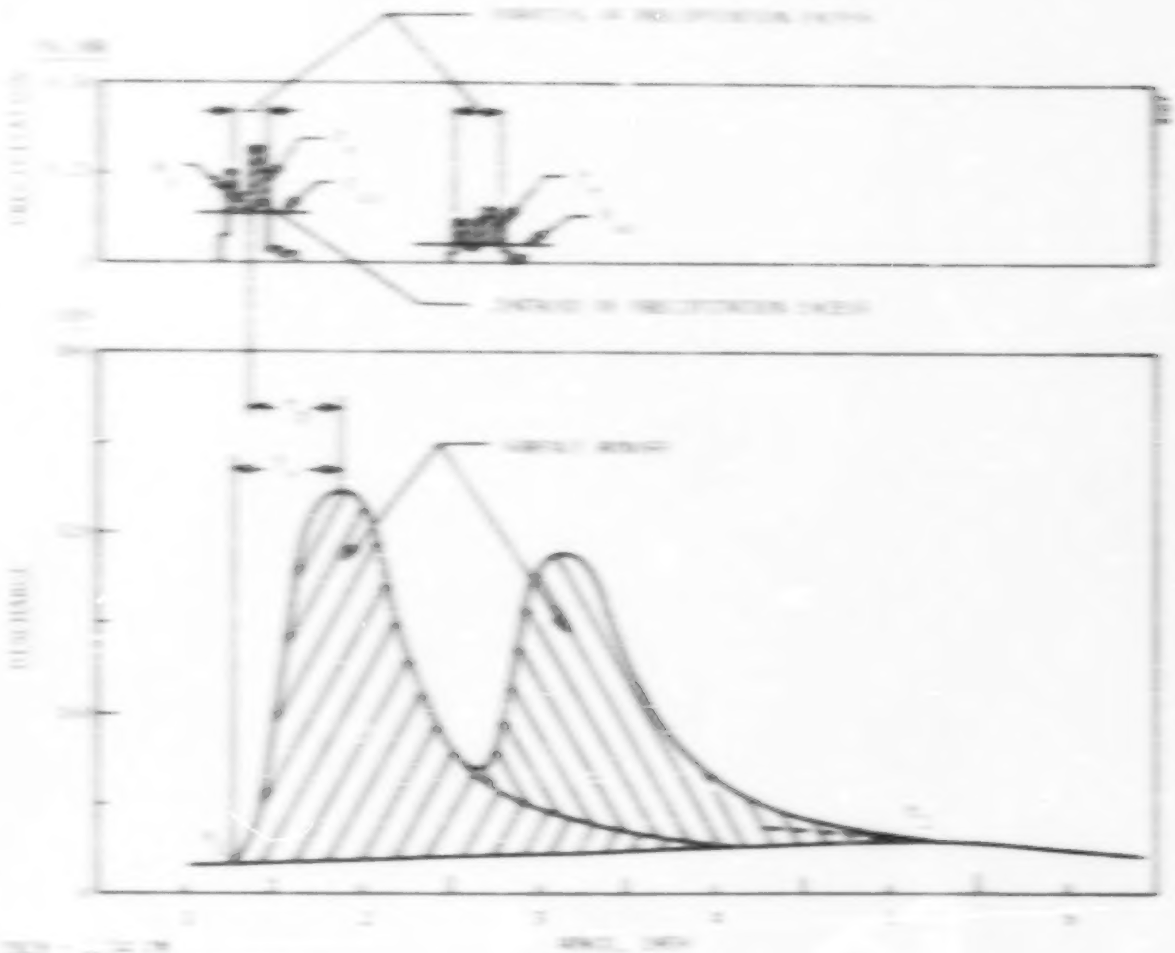


FIGURE D-3
TYPICAL STORM HYETOGRAPH AND HYDROGRAPH

To illustrate some of the problems in measuring storm runoff in small basins, peak flows exceeding 85 cubic meters per second per 260 hectares (3000 cfs per square mile) have been observed. Lag times (t_p) of 15 minutes to a hydrograph peak of about 28 cubic meters per second (1000 cfs) from a 600-hectare (2.3 sq mi) area are not uncommon. With such rapid changes in the flow, only highly responsive flow measurement methods can be used. The high rates of flow, with accompanying high velocities, further limit the usable flow measuring methods.

All flow data must be synchronized with time, at least on a watch time basis, to have any useful meaning. A particular need for attention to the time element occurs in the measurement of flows from small urban storm sewers in order to define the hydrograph and to provide data for the development and verification of rainfall-runoff-quality models. Peak flows, storm runoff volumes, daily flows, or other flow parameters are often correlated with similar flows at other points on a storm sewer or stream, or with flows of other storm sewers or streams, to provide a means for flow estimation. Correlations with temperature, soil moisture, or antecedent precipitation may be made at times. In most cases, it is essential that the correlated variables be synchronous, so accurate timing of the data is often required. It is mandatory if time-series analysis is contemplated.

Timing of measured flows and collection of quality samples can be useful in determining sources of pollution. For example, they can be related to time of release of pollutants from industrial plants, or to the time of accidental spills of pollutants. The time of travel of pollutants along a stream or storm sewer can be estimated from the time of travel of small rises or other flow changes in the channel.

D.3.2 Flow Measurement Equipment

This brief discussion is intended to provide an overview to aid the 208 planner in the selection of equipment for the quantitative measurement of flows. For further reading, see Shelley and Kirkpatrick (8), ASME (9), Replogle (10), McMahon (11), USDI Bureau of Reclamation (12), Leupold and Stevens (13), and any of the many standard texts on hydraulics and fluid mechanics.

Any flow measurement system consists of two distinct parts, each having a separate function to perform. The first, or primary element, is that part of the system which is in contact with the fluid, resulting in some type of interaction. The secondary element is that part of the system which translates this interaction into the desired readout or recording. While there is almost an endless variety of secondary elements, primary elements are related to a more limited number of physical principles, being dependent upon some property of the fluid other than, or in addition to, its volume or mass such as kinetic energy, inertia, specific heat, or the like. These primary element physical principles form a natural classification system for flow-measuring devices as presented in Table D-11.

D.3.2.1 Desirable Equipment Characteristics

Not all types of flow meters are suitable for measuring wastewater flows. The severe conditions and vagaries of many of these flows place a number of very stringent design requirements on flow measurement equipment if it is to function satisfactorily. No single design can be considered ideal for all flow measurement activities in all flows of interest. Despite this, one can set forth some equipment "requirements" in the form of primary design considerations and some desirable equipment features in the form of secondary design considerations.

The following are primary design considerations for equipment that is to be used to measure more difficult wastewaters such as storm and combined sewer flows:

1. Range. Since flow velocities may range from 0.03 to 9 m/s (0.1 to 30 fps), it is desirable that the unit have either a very wide range of operation, be able to automatically shift scales, or otherwise cover at least a 10 to 1 range.

TABLE D-11
FLOW METER CATEGORIZATION

Division	Classification	Type	Subtype
Quantity	Gravimetric	Weigher	
Quantity	Gravimetric	Tilting Trap	
Quantity	Gravimetric	Weight Dump	
Quantity	Volumetric	Metering Tank	
Quantity	Volumetric	Reciprocating Piston	
Quantity	Volumetric	Oscillating or Ring Piston	
Quantity	Volumetric	Nutating Disc	
Quantity	Volumetric	Sliding Vane	
Quantity	Volumetric	Rotating Vane	
Quantity	Volumetric	Gear or Lobed Impeller	
Quantity	Volumetric	Dethridge Wheel	
Rate	Differential Pressure	Venturi	
Rate	Differential Pressure	Dall Tube	
Rate	Differential Pressure	Flow Nozzle	
Rate	Differential Pressure	Rounded Edge Orifice	
Rate	Differential Pressure	Square Edge Orifice	Concentric
Rate	Differential Pressure	Square Edge Orifice	Eccentric
Rate	Differential Pressure	Square Edge Orifice	Segmental
Rate	Differential Pressure	Square Edge Orifice	Gate or Variable Area
Rate	Differential Pressure	Centrifugal	Elbow or Long Radius Bend
Rate	Differential Pressure	Centrifugal	Turbine Scroll Case
Rate	Differential Pressure	Centrifugal	Guide Vane Speed Ring
Rate	Differential Pressure	Impact Tube	Pitot Static
Rate	Differential Pressure	Impact Tube	Pitot Venturi
Rate	Differential Pressure	Linear Resistance	Pipe Section
Rate	Differential Pressure	Linear Resistance	Capillary Tube
Rate	Differential Pressure	Linear Resistance	Porous Plug
Rate	Variable Area	Gate	
Rate	Variable Area	Cone and Float	
Rate	Variable Area	Slotted Cylinder and Piston	
Rate	Head Area	Weir	Sharp Crested
Rate	Head Area	Weir	Broad Crested
Rate	Head Area	Flume	Venturi
Rate	Head Area	Flume	Parshall
Rate	Head Area	Flume	Palmer Bowlus
Rate	Head Area	Flume	Diskin Device
Rate	Head Area	Flume	Cutthroat
Rate	Head Area	Flume	San Dimas
Rate	Head Area	Flume	Trapezoidal
Rate	Head Area	Flume	Type HS, H, and HL
Rate	Head Area	Open Flow Nozzle	
Rate	Flow Velocity	Float	Simple
Rate	Flow Velocity	Float	Integrating
Rate	Flow Velocity	Tracer	
Rate	Flow Velocity	Vortex	Vortex Velocity
Rate	Flow Velocity	Vortex	Eddy Shedding
Rate	Flow Velocity	Turbine	
Rate	Flow Velocity	Rotating Element	Horizontal Axis
Rate	Flow Velocity	Rotating Element	Vertical Axis
Rate	Force Displacement	Vane	
Rate	Force Displacement	Hydrometric Pendulum	
Rate	Force Displacement	Target	
Rate	Force Displacement	Jet Deflection	
Rate	Force Displacement	Ball and Tube	
Rate	Force Momentum	Axial Flow Mass	
Rate	Force Momentum	Radial Mass	
Rate	Force Momentum	Gyroscopic	
Rate	Force Momentum	Magnus Effect	
Rate	Thermal	Hot Tip	
Rate	Thermal	Cold Tip	
Rate	Thermal	Boundary Layer	
Rate	Other	Electromagnetic	
Rate	Other	Acoustic	
Rate	Other	Doppler	
Rate	Other	Optical	
Rate	Other	Dilution	
Rate	Other	Electrostatic	
Rate	Other	Nuclear Resonance	

2. Accuracy. For most purposes, an accuracy of ±10 percent of the reading at the readout point is necessary, and there will be applications where an accuracy of ±5 percent is highly desirable. Repeatability of better than ±2 percent is desired in almost all instances.

3. Flow Effects on Accuracy. The unit should be capable of maintaining its accuracy when exposed to rapid changes in flow; e.g., depth and velocity changes in an open channel flow situation. There are instances where the flows of interest may accelerate from minimum to maximum in as short a time period as 5 minutes.

4. Gravity and Pressurized Flow Operation. Because of the conditions that exist at many measuring sites, it is sometimes desirable that the unit have the capability (within a closed conduit) of measuring over the full range of open channel flow as well as the conduit flowing full and under pressure.

5. Sensitivity to Submergence or Backwater Effects. Because of the possibility of changes in flow resistance downstream of the measuring site due to blockages, rising river stages including possible reverse flow, etc., it is highly advantageous that the unit be able to continue to function under such conditions or, at a minimum, be able to sense the existence of such conditions which would lead to erroneous readings.

6. Effects of Solids Movement. The unit should not be seriously affected by the movement of solids such as sand, gravel, debris, etc., within the fluid flow.

7. Flow Obstruction. The unit should be as nonintrusive as possible to avoid obstruction or other interference with the flow, which could lead to flow blockage or physical damage to some portion of the device.

8. Head Loss. To be usable at a maximum number of measurement sites, the unit should induce as little head loss as possible.

9. Manhole Operation. To allow maximum flexibility in utilization, the unit should have the capability of being installed in confined and moisture-laden spaces such as sewer manholes.

10. Power Requirements. The unit should require minimum power at the measuring site to operate; the ability to operate on batteries is a definite asset for many installations.

The following secondary design considerations are desirable features for flow measuring equipment.

Site Requirements. Unit design should be such as to minimize site requirements, such as the need for a fresh water supply, a vertical drop, excessive physical space, etc.

Installation Restrictions or Limitations. The unit should impose a minimum of restrictions or limitations on its installation and be capable of use on or within sewers of varying size.

Simplicity and Reliability. To maximize reliability of results and operation, the design of the unit should be as simple as possible, with a minimum of moving parts, etc.

Unattended Operation. For the majority of applications, it is highly desirable that the equipment be capable of unattended operation.

Maintenance Requirements. The design of the equipment should be such that routine maintenance is minimal and troubleshooting and repair can be effected with relative ease, even in the field.

Adverse Ambient Effects. The unit should be unaffected by adverse ambient conditions such as high humidity, freezing temperatures, hydrogen sulphide or corrosive gases, etc.

Submersion Proof. The unit should be capable of withstanding total immersion without significant damage.

Ruggedness. The unit should be of rugged construction and as vandal and theft proof as possible.

Self Contained. The unit should be self contained insofar as possible in view of the physical principles involved.

Precalibration. In order to maximize the flexibility of using the equipment in different settings, it is desirable that it be capable of precalibration; i.e., it should not be necessary to calibrate the system at each location and for each application.

Ease of Calibration. Calibration of the unit should be a simple, straightforward process requiring a minimum amount of time and ancillary equipment.

Maintenance of Calibration. The unit should operate accurately for extended periods of time without requiring recalibration.

Adaptability. The system should be capable of: indicating and recording instantaneous flow rates and totalized flows; providing flow signals to associated equipment (e.g., an automatic sampler); implementation of remote sensing techniques or incorporation into a computerized urban data system, including a multisensor single readout capability.

Cost. The unit should be affordable both in terms of acquisition and installation costs as well as operating costs, including repair and maintenance.

It is not necessary that all of these primary and secondary design considerations be achieved for all applications. For example, flow measurement devices used to calibrate others need not necessarily be self-contained, nor would unattended operations be required. Furthermore, meeting all of the listed design considerations for all installations and settings would be difficult, if not impossible, to achieve in a single design. Nonetheless, the primary and secondary design considerations can be used to formulate a set of evaluation parameters against which a given design or piece of equipment can be judged. Since application details may make certain parameters more or less important in one instance or another, no attempt has been made to apply weighting factors or assign numerical rank. The evaluation factors should prove useful, as a check list among other things, for the 208 planner who has a flow measurement requirement and who may require assistance in the selection of his equipment. The evaluation parameters together with qualitative scales, are presented in the form of a flow measurement equipment checklist in Table D-12.

D.3.2.2 Evaluations of Some Promising Devices

A slightly modified form of the flow measurement equipment checklist given in Table D-12 has been used to evaluate the various flow-measuring devices and techniques of Table D-11, and a matrix summary is given as Table D-13. It must be emphasized that these evaluations are made with a highly variable wastewater application such as storm or combined sewer flow measurement in mind and will not necessarily be applicable for other types of flows.

Only a few of the evaluation parameters normally have numbers associated with them. To assist the reader in interpreting the ratings, the following general guidelines were used. If the normal range of a particular device was considered to be less than about 10 to 1, it was termed poor; if it was considered to be greater than around 100 to 1, it was termed good. The intermediate ranges were termed fair. The accuracy that might reasonably be anticipated in measuring storm or combined sewer flows was considered rather than the best accuracy achievable by a particular device. For example, although a sharp-crested weir may be capable of achieving accuracies of ±1.5 percent or better in clear irrigation water flows, accuracies of much better than ±4 to 7 percent should not necessarily be anticipated for a sharp-crested weir measuring stormwater or combined sewer discharges. If the accuracy of a particular flow-measuring device or method was considered to be better than around ±1 to 2 percent, it was termed good; if it was considered

TABLE D-13
FLOW MEASUREMENT EQUIPMENT CHECKLIST

Designation: ____

Evaluation Parameter		Scale						Weight and Score
1	Range	☐	Poor	☐	Fair	☐	Good	
2	Accuracy	☐	Poor	☐	Fair	☐	Good	
3	Flow Effects on Accuracy	☐	High	☐	Moderate	☐	Slight	
4	Gravity & Pressurized Flow Operation	☐	No			☐	Yes	
5	Submergence or Backwater Effects	☐	High	☐	Moderate	☐	Low	
6	Effect of Solids Movement	☐	High	☐	Moderate	☐	Slight	
7	Flow Obstruction	☐	High	☐	Moderate	☐	Slight	
8	Head Loss	☐	High	☐	Medium	☐	Low	
9	Manhole Operation	☐	Poor	☐	Fair	☐	Good	
10	Power Requirements	☐	High	☐	Medium	☐	Low	
11	Site Requirements	☐	High	☐	Moderate	☐	Slight	
12	Installation Restrictions or Limitations	☐	High	☐	Moderate	☐	Slight	
13	Simplicity and Reliability	☐	Poor	☐	Fair	☐	Good	
14	Unattended Operation	☐	No	☐		☐	Yes	
15	Maintenance Requirements	☐	High	☐	Medium	☐	Low	
16	Adverse Ambient Effects	☐	High	☐	Moderate	☐	Slight	
17	Submersion Proof	☐	No			☐	Yes	
18	Ruggedness	☐	Poor	☐	Fair	☐	Good	
19	Self Contained	☐	No			☐	Yes	
20	[illegible]	☐	No			☐	Yes	
21	Ease of Calibration	☐	Poor	☐	Fair	☐	Good	
22	Maintenance of Calibration	☐	Poor	☐	Fair	☐	Good	
23	Adaptability	☐	Poor	☐	Fair	☐	Good	
24	Cost	☐	High	☐	Medium	☐	Low	
25	Availability	☐	No			☐	Yes	

Comments:

to be worse than around ±10 percent, it was termed poor. The intermediate accuracies were termed fair.

The flow-measuring devices and techniques were not rated on two evaluation parameters, submersion proof and adaptability, because these factors are so dependent upon the design details of the secondary element selected by the user.

In comparison with Table D-13, Table D-14 offers a different (and even more subjective) comparison of the most promising primary devices or techniques. Each method is numerically evaluated in terms of its percent of achievement of several desirable characteristics. Dilution techniques as a class appear to be most promising of all. In view of the current state-of-the-art, however, their usefulness is probably greatest as a tool for in-place calibration of other primary devices. They have also been extremely useful for general survey purposes and have found some application as an adjunct to other primary devices during periods of extreme flow such as pressurized flow in a conduit that is normally open channel.

Acoustic open channel devices are also quite promising; but, because of their dependency upon the velocity profile and the frequently resulting requirement for several sets of transducers, they are presently only justifiable for very large flows in view of the expense involved. The usefulness of the Parshall flume is evidenced by its extreme popularity. The requirement for a drop in the floor is a disadvantage, and submerged operation may present problems at some sites. Known uncertainties in the head-discharge relations (possibly up to 5 percent) together with possible geometric deviations make calibration in place a vital necessity if high accuracy is required. Palmer-Bowlus type flumes are very popular overall. They can be used as portable as well as fixed devices in many instances, are relatively inexpensive, and can handle solids in the flow without great difficulty.

All point velocity measuring devices have been lumped together in the current meter category. In the hands of a highly experienced operator, good results can be obtained (the converse is also true, unfortunately), and they are

TABLE D-13
FLOWMETER EVALUATION SUMMARY

[illegible]

TABLE B-14
COMPARISON OF MOST POPULAR PRIMARY DEVICES OR TECHNIQUES

[illegible]	[illegible]								[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

often used to calibrate primary devices in place or for general survey work. They are generally not suited for unattended operation, however.

Electromagnetic flowmeters show considerable promise where pressurized flow is ensured, as do closed pipe acoustic devices. Neither can be considered portable if one requires that the acoustic sensors be wetted, a recommended practice for most wastewater applications.

Open flow nozzles and sharp-crested weirs are often used where the required head drop is available. Weirs will require frequent cleaning and are best used as temporary installations for calibration purposes. Flow tubes and venturis are only suitable for pressurized flow sites such as might be encountered, for example, at the entrance to a treatment plant.

Trajectory coordinate techniques, such as the California pipe or Purdue methods, require a pipe discharging freely into the atmosphere with sufficient drop to allow a reasonably accurate vertical measurement to be made, a situation not often encountered in sewers. Slope area methods (e.g., Manning formula) must generally be considered as producing estimates only, and consequently should be considered as the choice of last resort (despite their apparent popularity).

D.3.2.3 Review of Commercially Available Equipment and Costs

The number of commercial firms that offer liquid flow-measuring equipment in the marketplace today is astoundingly large, probably well in excess of 200. Many manufacturers offer more than one type of primary device (and these typically in numerous models) and, when combined with secondary device choices, the number is virtually overwhelming. Thus, no attempt to cover all available equipment can be made here. We simply note that two or more firms offer all devices that were described except for sharp-crested weirs, which are usually fabricated directly by (or for) the user in accordance with specifications for the particular measuring site.

The firms offering flow-measuring equipment as at least a part of their product line range from very large, well-known manufacturers that have offered a wide range of flow-measuring equipment for over a century to relatively small organizations with a limited product line that has only recently been introduced. This latter category should not be excluded from consideration solely because of their seemingly novitiate status. The principals involved frequently have many years of experience, and their designs often reflect the most up-to-date expressions of the state-of-the-art.

The revolution in the electronics industry, especially as regards solid-state designs and integrated circuitry, has not gone unnoticed by most flowmeter manufacturers; as a result, many new, sophisticated secondary devices have recently appeared, and older equipment is frequently being upgraded in design to reflect the more modern technologies. Furthermore, many of these new secondary devices are of digital (rather than analog) design and are frequently computer compatible as supplied, offering tremendous possibilities for system structure.

A listing, by no means complete, of some manufacturers who offer flow-measuring equipment in the categories listed in Table D-14 is presented in Table D-15. Under the heading "Company," the name, address, and telephone number have been provided. Under the heading "Products" only those products bearing on the flow measurement categories of Table D-14 have been listed, even though the particular company may have a much more extensive flow measurement product line. The product emphasis was placed on primary devices, with secondary devices (in the form of level gages) indicated only where they are offered as "flowmeters." It can be generally assumed that each manufacturer offers a complete line of secondary elements for use with his primary devices.

Table D-15 can be used to obtain direct, up-to-date information on all of the types of equipment discussed from at least two suppliers. Reference can be made to Shelley and Kirkpatrick (8) for descriptions of the offerings of these and a number of other manufacturers.

TABLE 3-15
SOME FLOW MEASUREMENT EQUIPMENT MANUFACTURERS

[illegible]

TABLE [illegible]

SOME FLOW MEASUREMENT EQUIPMENT MANUFACTURERS (Cont'd)

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

In these days of inflation, little can be said about equipment costs except in a very cursory fashion. For example, one manufacturer is anticipating a 30-percent increase in the cost of basic flow tube forgings, catalog pricing is giving way to individual quotes for larger systems, and some manufacturers are quoting tentative estimates subject to adjustment at delivery. Desired features such as remote readouts, digital outputs, recorder types, battery parts, etc., add another dimension to total system costs. The following discussion is more indicative than precise, and all costs must be increased if many accessories are desired.

Dilution flow measurement systems can be put together for under $3K. The chemicals (salt, dye, etc.) are inexpensive. Acoustic open channel devices start at around $5K, and larger systems are quoted on an installation basis only, with $15-40K being a typical charge for a four-path system and some large, complex installations approaching $100K in cost. Parshall flumes run from $300 to over $2K in portable versions, depending upon size, and from $500 to $5K for fixed installations, not counting secondary devices. Palmer-Bowlus flumes without a level gage will cost between $300 and $3K depending upon size. Construction materials also affect flume prices.

Simple current meters start at around $300 for basic Price or Ott types and may run as high as $1,500. Electromagnetic current meters cost from $2K to $3K. Electromagnetic pipe meters start at around $2K for small (2 in.) sizes and run to over $30K in the largest practicable sizes. Acoustic pipe meters run from $2K to $20K depending upon size. These prices are for complete systems including secondary devices.

Open flow nozzles, flow tubes, and Venturi tubes are comparably priced with forging costs and machining accounting for the major portion. In small sizes (3 in.) they run under $1K, and range up to $15-20K in large sizes (18 in.). These prices do not include secondary devices.

The liquid level gage market is intensely competitive at the present time, and prices are similar regardless of technique (e.g., electronic, bubble, acoustic, dipper, etc.). They run from just under $1K for a basic device with visual read-out to over $2K with flow converters, recorders, transmitters, etc., as accessories.

As a closing note, construction, installation, and (importantly) projected maintenance and repair costs must be considered in addition to the equipment acquisition costs given above to arrive at true cost of ownership, which is the only real basis for comparison.

D.3.2.4 Review of Recent Field Experience

A brief review of flow measurement experiences, with emphasis on recent projects in the storm and combined sewer area, will be given to allow a better appreciation of the application of some of the flow-measuring devices and techniques in an actual field setting. The various experiences are presented by primary device or technique as listed in Table D-13. It should be pointed out that, although the following discussion focuses more on the negative experiences, instances of good results were encountered with all types of flow measurement.

Dilution methods were successfully used to calibrate primary devices in several instances. In one installation, this technique was used to measure flows in a sewer under surcharged conditions. A Palmer-Bowlus flume was employed for normal flow conditions. When the secondary device indicated that the sewer line was nearly filled, a signal was given to begin chemical injection. An automatic sampler was used to obtain samples for concentration analysis at a site downstream from the injection equipment. Some other attempts to use dilution methods were less successful, and it was abandoned by several projects. Erroneous effects due to exposed sludge banks, insufficient turbulence to ensure mixing, and poor equipment operation (especially samplers) were among difficulties cited.

Open channel acoustic devices had rather little use in the projects examined because of their recent origin. Although successful installations exist, their use has been abandoned at other locations. The primary difficulties have to do with particles, notably air bubbles, in the flow causing improper readings, the complex velocity patterns requiring a number of transverse sensors, and simple shakedown difficulties typical of early designs of many complex electronic devices. Acoustic level gages were plagued by wind (in an open application), foam, standing ripples on the water surface, and false echoes from manhole structures or other confined areas. More recent indications are that such problems are being overcome, and satisfaction with these devices appears to be increasing.

Parshall flumes were used in many projects, and they performed well when dimensions were faithfully followed, standard approach conditions were present, and (especially) when calibrated in place. Unfortunately, far too many Parshall flume installations are nonstandard, reflecting difficulties in making precise structures from poured concrete, the improper use of a lightweight plastic flume liner as a form, etc.

Palmer-Bowlus type flumes were successfully used in a number of instances, including portable versions intended for short-time application at any given site. Other than their loss of accuracy as the pipe fills and surcharges, no general negative comments about the devices themselves were encountered. There were numerous complaints concerning secondary devices used in conjunction with Palmer-Bowlus flumes, however, especially bubblers. Instances of their collecting debris and otherwise requiring frequent cleaning and maintenance abound. In one project, their use was abandoned altogether, and they were replaced with another type of level sensor.

Current meters were almost exclusively used to spot check flows and verify or rate existing structures. There were flows where they could not be used at all, however, because they immediately became fouled by rags, plastic sheets, and other debris.

Electromagnetic devices were not encountered, except where they had already been installed for other purposes. They appeared to work well, but the need for periodic inspection and verification of any fixed flow-measuring device was illustrated at one installation. As a part of a general flowmeter inspection in one district an apparently well performing electromagnetic flowmeter was found to be in error by over 30 percent. The cause was a piece of utility pole resting in the meter proper.

No projects examined used pressure flow acoustic meters, but their use in industrial plant applications has apparently been successful in many instances. Open flow nozzles performed rather well where sites allowed their use. Frequent inspection and cleaning were required at several installations, however, to ensure proper readings.

Sharp-crested weirs were among the most commonly used (and misused) primary devices encountered. Problems ranged from failure to properly account for approach velocity, improper sizing, backwater elevations causing surcharging and flooding, to almost continual cleaning being required in very trashy flows.

Flow tubes and venturi tubes were seldom encountered, except where they had existed for other purposes. They generally seemed to produce complete and accurate records.

Trajectory coordinate estimates were uncommon, owing to the lack of suitable sites.

Slope-area methods (Manning in particular) were far and away the most frequently encountered. They ranged from proper applications yielding reasonable discharge estimates to totally unsuitable applications, as in one case where the combined sewer discharge was found to considerably exceed the measured precipitation event. Difficulties ranged from accurately measuring slopes to estimating the proper friction coefficient (n) to use, in the best instances, to unknowledgeable attempts and improper applications in the worst. Apparently, far too many persons think that all that has to be done is to measure stage and plug into a handy formula to obtain flow. It is long past time that that situation be corrected.

D.3.3 Flow Measurement Field Procedures

For flow measurement in natural streams and channels, it is recommended that USGS assistance be obtained. They will establish gaging stations (temporary or permanent) at reasonable cost upon request and provide ratings to convert stage to discharge. Often a culvert or some other control structure for which a theoretical rating can be developed will be used. In some instances, weirs or flumes will have to be used. It is prudent to spot check the ratings of new gaging stations periodically. Be alert to changes in channel characteristics that would affect the established rating, e.g., sedimentation, erosion, deposition of large stones or boulders, etc.

Follow the manufacturer's recommendations for the installation, calibration, and operation of the liquid level gages used to record stage. Where stilling wells are employed, the connecting pipe should be checked for obstruction on each visit, as should the float and cable operation. Note any instances that could affect readings in the field log and the corrective action taken. It is also prudent to verify chart time at each visit if record length exceeds visit frequency (e.g., weekly flow charts but daily sampling). If a manual sample is taken, a mark made on the flow chart can assist in subsequent data analysis.

For manually gaging natural streams at the time of sampling, follow the guidance given by the Bureau of Reclamation (12). Do not take a stream gaging until all required samples for the site have been collected. Try to minimize or avoid walking in the stream until sampling is completed. Stirring up the bottom may result in nonrepresentative samples. A complete flow record is more desirable, however, and flow determinations made manually at the time of sampling should be considered as a last choice.

For flow measurement in man-made channels and conduits, the use of an appropriate primary device (refer to discussion in section D.3.2) is recommended. These should be properly installed, following manufacturer's recommendations in the case of commercial devices. The Bureau of Reclamation

Manual (17) provides much helpful information. An independent verification of the installation (i.e., by someone not on the installation team) will be prudent in most instances. This is especially true where existing flow-metering stations are to be used. Checklists for each type of primary device should be prepared to facilitate field inspection. As an example, a check-list for a contracted rectangular weir is presented in Table D-16.

Comments made above for secondary devices apply here as well. In closed conduits that are subject to occasional surcharging, try to install the level gage so that it will indicate when this condition occurs. Although the degree of surcharging cannot be indicated by most designs, knowledge of the period of time over which the surcharge condition exists may be helpful in subsequent data analysis. Such sites are best avoided wherever possible, however.

On each visit, the flow-measuring equipment should be inspected to ensure proper functioning. Visual verification of stage readings with a staff gage is recommended at each visit, and results should be noted in the field log, along with any anomalies discovered (e.g., a rag caught in the notch of a weir, a stuck float, a clogged stilling well connection tube, etc.) and any corrective actions taken. The possible buildup of sediment behind a weir should be checked (the staff gage can be used) and any accumulation removed. An occasional in-place calibration check is recommended to ensure that subtle changes that could affect the record have not occurred.

One word of caution as regards the use of sewer maps is in order. Typically, such maps (elevations especially) reflect intentions rather than installations. Even so-called as-built drawings may only indicate average invert slopes from manhole to manhole and tell little about variations in true slope. It is generally a prudent practice to verify pipe slopes entering and leaving manholes where flow measurements are to be made.

Flow measurement at outfall sites can present some unique difficulties. Where there is a drop from the discharge pipe invert to the upper level of the receiving stream, the site will probably be acceptable, and a temporary

TABLE D-16
CHECKLIST FOR CONTRACTED RECTANGULAR WEIR

1. What is the maximum measurable head? ______
2. Is upstream face of bulkhead smooth? ☐
3. Is upstream face of bulkhead vertical? (check for plumb with level) ☐
4. Is upstream face of weir plate smooth, straight, and flush with upstream face of bulkhead? ☐
5. Is weir axis perpendicular to channel axis? (check with line and carpenter's square) ☐
6. Is entire crest level? ☐
7. What is thickness of crest in flow direction? (should be between 0.03 and 0.08 inch) ______
8. Is upstream corner of crest sharp and at right angles to upstream face? ☐
9. Are both side edges truly vertical and of same thickness as crest? ☐
10. Are downstream edges of notch chamfered? (angle should be 45° or more to crest surface) ☐
11. What is distance of crest from bottom of approach channel? (should be at least twice the depth above the crest and never under one foot) ______
12. What is distance from sides of weir to sides of approach channel? (should be at least twice the depth above the crest and never under one foot) ______
13. Does nappe touch only the upstream edges of the crest and sides? Is nappe free? Is there free fall? ☐
14. Does zero head reading match with crest elevation? ☐
15. Is head reading taken upstream a distance of at least 3 times the maximum head on the crest? ☐
16. Is the cross-sectional area of the approach channel at least 8 times that of the nappe? ☐
17. Does this condition extend upstream at least 15 times the depth above the crest? ☐
18. If weir pool is smaller than defined above, measure velocity of approach with current meter. ______
19. If appreciable velocity of approach is measured are head readings being corrected? ☐

weir box can be installed and used satisfactorily. Where the receiving stream level is above the invert but below the crown, a pipe extension and Palmer-Bowlus flume (or a Parshall flume in some instances) can possibly be used. The real problem occurs where the outfall is completely submerged, and the expense of a permanent device such as an electromagnetic flow meter (otherwise, an excellent choice for such a site since it can measure flow in either direction) cannot be tolerated. The best advice is to find another site. If that cannot be done, the only recourse is to use a current meter to obtain a velocity, adjust this to an average value, and multiply by the pipe area to obtain flow. Where there is insufficient debris in the flow to cause problems in operation, an oceanographic type recording current meter or some other recording point velocity sensor can be used. For very trashy flows, the only solution may be to measure velocities manually, cleaning up the current meter between observations. This approach may be acceptable for some intermittent discharges if a man can get to the site on time, but continuous records are impracticable.

D.4 Sampling Considerations, Equipment, and Procedures

The objective of any sampling effort is to remove, from a defined universe, a small portion that is in some way representative of the whole. Ideally, a representative sample will accurately reflect the physical and chemical characteristics of the bulk source in every respect as they were during the sampling period. In water quality, such representativeness is seldom if ever achieved and, fortunately, seldom required. As used herein, a representative sample is one that, when examined for a particular parameter, will yield a value from which that bulk source characteristic can be determined. The proper sampling methodology, i.e., that which will produce a representative sample, is dependent upon the type of bulk source to be sampled, e.g., surface water in natural channels (rivers, streams, lakes), municipal wastewater, ground water, urban runoff, industrial wastewater, treatment lagoon, and so on. Nonetheless, there are some more or less universal sampling considerations, and they will now be addressed.

D.4.1 Sample Types

The selection of the type of sample to be collected depends on a number of factors, such as the rates of change of flow and the character of the water or wastewater, the accuracy required, and the availability of funds for conducting the sampling program. All samples collected, either manually or with automatic equipment, are included in the following types, which terminology has been recommended for standard usage by Shelley and Kirkpatrick (14).

Discrete Sample

A discrete sample (sometimes called a grab sample) is one that is collected at a selected point in time and retained separately for analysis. A sequential discrete sample is a series of such samples, usually taken at constant time intervals (e.g., one each hour over a 24-hour period), but sometimes at constant discharge increments (e.g., one for each 100,000 gallons of flow) when paced by a flow totalizer.

Simple Composite Sample

A simple composite sample is one that is made up of a series of aliquots (smaller samples) of constant volume (Vc) collected at regular time intervals (Tc) and combined in a single container. Such a sample could be denoted by TcVc, meaning time interval between successive aliquots constant and volume of each aliquot constant.

Flow Proportional Composite Sample

A flow proportional composite sample is one collected in relation to the flow volume during the period of compositing, thus indicating the "average" condition during the period. One of the two ways of accomplishing this is to collect aliquots of equal volume (Vc), but at variable time intervals (Tv), that are inversely proportional to the volume of the flow. That is, the time interval between aliquots is reduced as the volume of flow increases. Alternatively, flow proportioning can be achieved by increasing the volume of each aliquot in proportion to the flow (Vv), but keeping the time interval between aliquots constant (Tc).

Sequential Composite Sample

A sequential composite sample is composed of a series of short-period composites, each of which is held in an individual container. For example, each of several samples collected during a 1-hour period may be composited for the hour. The 24-hour sequential composite is made up from the individual 1-hour composites.

Continuous Sample

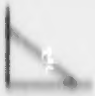
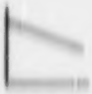
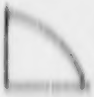
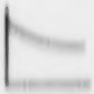
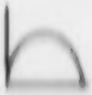
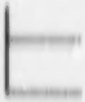
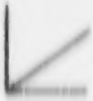
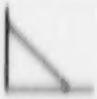
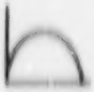
A continuous sample is one collected by extracting a small, continuously flowing stream from the bulk source and directing it into the sample container. The sample flow rate may be constant (Qc), in which case the sample is analogous to the simple composite, or it may be varied in proportion to the bulk source flow rate (Qv), in which case the sample is analogous to the flow proportional composite.

For initial characterization of wastewater flows, sequential discrete sampling is generally desired. It is mandatory for accurate stormwater characterization, since it allows characterization of the wastewater over a time history and provides information about its variations with time. If the samples are sufficiently large, manual compositing can also be performed, based on flow records or some other suitable weighting scheme, and a preferred composite type determined. Some form of automatic compositing will usually be desired for continued wastewater discharge characterization.

A brief look at the different types of composite samples is in order. Any scheme for collecting a composite sample is, in effect, a method for mechanically integrating to obtain average flow characteristics. The simple composite is the crudest attempt at such averaging and will be representative of the waste flow during the period only if the flow properties are relatively constant.

For variable flows, some type of proportioning must be used. This is equivalent to saying that the simple composite is a very poor scheme for numerical integration, and a higher order method is desirable. There are two fundamental approaches to obtaining better numerical integration, given a fixed number of steps. One is to increase the order of the integration scheme to be used, as in going from the trapezoidal rule to Simpson's rule. The other is to vary the step size in such a way as to lengthen the steps when slopes are changing very slowly and shorten them when slopes change rapidly. Typical of the first approach are the constant time interval, variable volume (TcVv) proportional composites. There are two straightforward ways of accomplishing this. One is to let the aliquot volume be proportional to the instantaneous flow rate, and the other is to make the aliquot volume proportional to the quantity of flow that has passed since extraction of the last aliquot. Typical of the second approach is the variable time interval, constant volume (TvVc) proportional composite. Here a fixed volume aliquot is taken each time an arbitrary quantity of flow has passed.

It is instructive to compare these four composite sample schemes. For the purposes of this example, four flow functions and five concentration functions are examined. The selections are completely arbitrary (except for simplicity in exact integration) and, in practice, site specific data should be used. For each flow/concentration combination, the exact average concentration of the flow was computed (as though the entire flow stream were diverted into a large tank for the duration of the event and then its concentration measured). The ratio of the composite sample concentration to the actual concentration so computed is presented in matrix form in Figure D-4 (taken from Shelly and Kirkpatrick, 15). The four rows in each cell represent the four types of composite samples discussed as indicated in the legend. The best overall composite for the cases examined is the TcVv, with the volume proportional to the instantaneous flow rate q. The TcVv where the volume is proportional to the flow since the last sample, and the TvVc gave very similar results with a slight edge to the former. However, the differences are not large for any case. This brief look at compositing merely scratches the surface. Flow records and a knowledge of the temporal

CONC ↓ q FLOW	 1-t	 $1-\frac{t}{2}$	 $\cos\frac{\pi t}{2}$	 e^{-t}	 sinπt
 C	0.90 0.90 0.90 0.90	0.97 0.97 0.97 0.97	0.92 0.92 0.92 0.92	0.95 0.95 0.95 0.95	0.99 0.99 0.99 0.99
 t	1.35 0.90 0.86 0.87	1.09 0.97 0.96 0.96	1.26 0.90 0.87 0.89	1.14 0.37 0.95 0.95	0.99 0.90 0.89 0.97
 1-t	0.68 0.95 0.92 0.92	0.87 0.98 0.97 0.97	0.72 0.98 0.95 0.93	0.82 0.96 0.95 0.95	0.99 1.12 1.09 0.97
 sinπt	0.90 1.01 0.90 0.90	0.97 1.00 0.97 0.97	0.88 1.00 0.92 0.92	0.97 1.60 0.95 0.95	0.80 1.01 0.98 0.97

The rows within each flow/concentration cell refer to the following sample types:

Row 1. TcVc - Simple composite
Row 2. TcVv - Volume proportional to flow rate (q)
Row 3. TcVv - Volume proportional to flow (Q) since last sample
Row 4. TvVc - Time varied to give constant ΔQ

FIGURE D-4
RATIO OF COMPOSITE SAMPLE CONCENTRATION TO
ACTUAL CONCENTRATION

fluctuation of pollutants, as can be obtained from discrete samples, are required in order to choose a "best" compositing scheme for a given installation.

Continuous samples are also composite in nature but do not fit in the foregoing discussion since the discrete step integration analogy is not applicable. Had we included the Qv continuous sample in the foregoing example, its ratio would have been unity for all combinations in Figure D-4. Other considerations severely limit the instances where a continuous sample is the composite of choice. For wastewater sampling, it is generally agreed that the minimum line inside diameter is 0.6 cm (1/4 in.) and that the sample flow velocity should be at least 0.76 m/s (2.5 fps). A simple calculation shows that the minimum volume of a 24-hour continuous sample would be 2085 liters (551 gal), hardly a practicable size. For this reason, continuous samples are useful only for very pristine flows (e.g., drinking water), where the very low flow rates necessary to keep sample volumes reasonable may still allow a representative sample to be obtained.

D.4.2 Automatic Sampling Equipment

In the following, a systems breakdown of automatic sampling equipment is given in generic terms to allow the reader to better appreciate their functional purposes and requirements. A survey of commercially available automatic sampling equipment and costs is given, and a review of field experience with these devices is provided.

D.4.2.1 Elements of an Automatic Sampler System

In a system breakdown by functional attributes, an automatic liquid sampler may be divided into five basic elements or subsytems. Each of these will be discussed in turn.

D.4.2.1.1 Sample Intake Subsystem

The operational function of the sample intake is to reliably allow the gathering of a representative sample from the flow stream in question. Its reliability is measured in terms of freedom from plugging or clogging, to the degree that sampler operation is affected, and invulnerability to physical damage due to large objects in the flow. It is also desirable, from the viewpoint of sewer operation, that the sample intake offer a minimum obstruction to the flow in order to reduce the possibility of blockage of the entire pipe by lodged debris, etc.

The sample intake of many commercially available automatic liquid samplers is often only the end of a plastic suction tube, and the user is left to his own ingenuity and devices if he desires to do anything other than simply dangle the tube in the stream to be sampled. Some manufacturers provide a weighted, perforated plastic cylinder that screens the hose inlet from the unwanted material that might cause choking or blockage elsewhere within the sampler. Typical hole sizes are around 1/3 cm (1/8 in.) in diameter and, if there are sufficient holes to ensure free flow, results have been satisfactory in some applications. Samplers that employ pneumatic ejection have their own intake chambers that must be used in order for the equipment to function properly.

D.4.2.1.2 Sample-Gathering Subsystem

Three basic sample-gathering methods or categories can be identified: mechanical, forced flow, and suction lift. The sample lift requirements of the particular site often play a determining role in the gathering method to be employed.

Mechanical Methods. There are many examples of mechanical gathering methods used in both commercially available and one-of-a-kind samplers. One of the more common designs is the cup on a chain driven by a sprocket drive arrangement. In another design, a cup is lowered within a guide pipe, via a small automatic winch and cable. Other examples include a self-closing pipe-like device that extracts a vertical "core" from the flow stream, a specially contoured box assembly with end closures that extracts a short length (plug) of the entire flow cross section, and a revolving or oscillating scoop that traverses the entire flow depth.

Some of the latter units employ scoops that are characterized for use with a particular primary flow measurement device, such as a weir or Parshall flume, and extract an aliquot volume that is proportional to the flow rate. Another design for mechanically gathering flow-proportional samples involves the use of a sort of Dethridge wheel with a sample cup mounted on its periphery. Since the wheel rotation is proportional to flow, the effect is that a fixed volume aliquot is taken each time a certain discharge quantity has passed, and total discharge can be estimated from the size of the resultant composite sample.

The foregoing designs have primarily arisen from one of two basic considerations: (1) site conditions that require very high lifts, or (2) the desire to gather samples that are integrated across the flow depth. One of the penalties that must be traded off in selecting a mechanical gathering unit is the necessity for some obstruction to the flow, at least while the sample is being taken. The tendency for exposed mechanisms to foul, together with the added vulnerability of many moving parts, means that successful operation will require periodic inspection, cleaning, and maintenance.

Forced Flow Methods. All forced flow gathering methods require some obstruction to the flow, but usually it is less than with mechanical gathering methods. It may be only a small inlet chamber with a check valve assembly of some sort, or it may be an entire submersible pump. The main advantage of submersible pumps is that their high discharge pressures allow sampling at greater depths, thereby increasing the flexibility of the unit somewhat, insofar as site depth is concerned. Pump malfunction and clogging, especially in the pump sizes often used for samplers, is always a distinct possibility; because of the pump's location in the flow stream itself, maintenance is much more difficult and costly to perform than on above-ground or more easily accessible units. Submersible pumps also necessarily present an obstruction to the flow and are thus in a vulnerable position as regards damage by debris.

Pneumatic ejection is a forced flow gathering method used by a number of commercial samplers. The gas source required by these units varies from bottled refrigerant to motor-driven air compressors. The units that use bottled refrigerant must be of a fairly small scale to avoid an enormous appetite for the gas and, hence, a relatively short operating life before the gas supply is exhausted. Furthermore, concern has recently been expressed about the quantities of freon that are being discharged into the atmosphere. The ability of such units to backflush or purge themselves is also limited. The advantages of few moving parts, inherent explosion-proof construction, and high lift capabilities must be weighed against low or variable line velocities, low or variable sample intake velocities, and relatively small sample capacities in some designs. Another disadvantage of many pneumatic ejection units is that the sample chamber fills immediately upon discharge of the previous sample. Thus, it may not be representative of flow conditions at the time of the next triggering and, if paced by a flow meter, correlation of results may be quite difficult.

Suction Lift Methods. Suction lift units must be designed to operate in the environment near the flow to be sampled or else their use is limited to a little over 9m (30 ft) due to atmospheric pressure. Several samplers that take their suction lift directly from an evacuated sample bottle are available today. Vacuum leaks, the variability of sample size with lift, the requirement for heavy glass sample bottles to withstand the vacuum, the difficulty of cleaning due to the requirement for a separate line for each sample bottle, the necessity of placing the sample bottles near the flow stream (and hence in a vulnerable position), and the varying velocities as the sample is being withdrawn, are among the many disadvantages of this technique.

Other units are available that use a vacuum pump and some sort of metering chamber to measure the quantity of sample being extracted. These units, in some designs, offer the advantages of fairly high sample intake and transport velocities. The fluid itself never comes in contact with the pump, and the pump output can easily be reversed to purge the sampling line and intake to help prevent cross-contamination and clogging.

A variety of positive displacement pumps have been used in the design of suction lift samplers, including flexible impeller, progressive cavity rotary screw, roller or vane, and peristaltic types. Generally these pumps are self-priming (as opposed to many centrifugal pumps), but some designs should not be operated dry because of internal wearing of rubbing parts. The desirability of a low-cost pump that is relatively free from clogging has led many designers to use peristaltic pumps. A number of types have been employed including finger, nutating, and two- and three-roller designs using either molded inserts or regular tubing. Most of these operate at such low flow rates, however, that the representativeness of suspended solids is questionable. Newer high-capacity peristaltic pumps are now available and are finding application in larger automatic samplers. The ability of some of these pumps to operate equally well in either direction affords the capability to blow down lines and help remove blockages. Also, they offer no obstruction to the flow since the transport tubing need not be interrupted by the pump, and strings, rags, cigarette filters, and the like are passed with ease.

All in all, the suction-lift gathering method appears to offer more advantages and flexibility than either of the others for many applications. The limitation on sample lift can be overcome by designing the pumping portion of the unit so that it can be separated from the rest of the sampler and thus positioned within 6m (20 ft) or so of the flow to be sampled. For many sites, however, even this will not be necessary.

D.4.2.1.3 Sample Transport Subsystem

The majority of the commercially available automatic samplers have fairly small line sizes in the sample train. Such tubes, especially at 1/3 cm (1/8 in.) inside diameter and smaller, are very vulnerable to plugging, clogging due to the buildup of fats, etc. For many applications, a better minimum line size would be 1 to 1.3 cm (3/8 to 1/2 in.) inside diameter.

For flows that are high in suspended solids, it is imperative that adequate sample flow rate be maintained throughout the sampling train in order to effectively transport them. In horizontal runs, the velocity must exceed the scour velocity while, in vertical runs, the settling or fall velocity must be exceeded several times to ensure adequate transport of solids in the flow. Sharp bends and twists or kinks in the sampling lines should be avoided if there is a possibility of trash or debris in the lines that could become lodged and restrict or choke the flow. The same is true of some valve designs. In summary, the sampling train must be sized so that the smallest opening is large enough to give assurance that plugging or clogging is unlikely in view of the material being sampled. However, it is not sufficient to simply make all lines large, which also reduces friction losses, without paying careful attention to the velocity of flow. For many applications, minimum velocities of 0.6 to 1 m/s (2 to 3 fps) would appear warranted, and even higher velocities are required for some applications.

B.4.2.1.4 Sample Storage Subsystem

The sample container itself should either be easy to clean or disposable. Although some of today's better plastics are much lighter than glass and can be autoclaved, they are not so easy to clean or inspect for cleanliness. Also, the plastics will tend to scratch more easily than glass and, consequently, cleaning a well-used container can become quite a chore.

The requirements for sample preservation are discussed elsewhere, but it should be noted here that refrigeration is stated as the best single preservation method and will, in all likelihood, be required unless the sampling cycle is brief and samples are retrieved shortly after being taken. Light can also affect samples, and either a dark storage area or opaque containers would seem desirable. If opaque containers are used, however, they should be disposable, since it would be difficult to inspect an opaque container for cleanliness.

B.4.2.1.5 Controls and Power Subsystem

The control aspects of some commercial automatic samplers have come under particular criticism. It is no simple matter, to provide great flexibility in operation of a unit while at the same time avoiding all complexities in its control system. The problem is not only one of component selection but of packaging as well. For instance, even though the possibility of immersion may be extremely remote in a particular installation, the corrosive, highly humid atmosphere, which will, in all likelihood, be present, makes sealing of control elements and electronics desirable in most instances.

The controls determine the flexibility of operation of the sampler, e.g., its ability to be paced by various types of flow-measuring devices. Built-in timers should be repeatable, and time periods should not be affected by voltage variations. The ability to repeatedly gather the required aliquot volume independent of flow depth or lift is very important if composite samples are to be collected. Provisions for manual operation and testing are desirable, as is a clearly laid out control panel. Some means of determining the time when discrete samples were taken is necessary if synchronization with flow records is contemplated. An event marker is desirable for a sampler that is to be paced by an external flow recorder. Reliability of the control system can dominate the total system reliability. At the same time, this element will, in all likelihood, be the most difficult to repair and calibrate. Furthermore, environmental effects will be the most pronounced in the control system.

The required tasks can be best executed, in the light of the current electronics state-of-the-art, by a solid-state controller element. Such designs offer higher inherent reliability and are becoming more and more common in commercially available samplers. In addition, the unit should be of modular construction for ease of modification, performance monitoring, fault location, and replacement/repair. Such an approach also lends itself to encapsulation, which will minimize environmental effects. Solid-state switching eliminates the possibility of burned or welded contacts, either of which will cause complete sampler breakdown.

Some automatic samplers available today require a 110V AC power supply, but many battery-operated units are also available. The latter are, of necessity, smaller in size and sample transport velocity but still have a wide range of application. Other portable units utilize compressed gas or spring motors as the only required power source.

D.4.2.2 Considerations in Automatic Sampler Selection

Presently available automatic liquid samplers have a great variety of characteristics with respect to size of sample collected, lift capability, type of sample collected (discrete or composite), materials of construction, and numerous other both good and poor features. A number of considerations in selection of a sampler are:

- Rate of change of wastewater conditions
- Frequency of change of wastewater conditions
- Range of wastewater conditions
- Periodicity or randomness of change
- Availability of recorded flow data
- Need for determining instantaneous conditions, average conditions, or both
- Volume of sample required
- Need for preservation of sample
- Estimated size of suspended matter
- Need for automatic controls for starting and stopping
- Need for mobility or for a permanent installation
- Operating head requirements

In addition to the foregoing attributes of automatic sampling equipment, there are also certain desirable features that will enhance the utility and value of the equipment. For example, the design should be such that maintenance and troubleshooting are relatively simple tasks. Spare parts should be readily available and reasonably priced. The equipment design should be such that the unit has maximum inherent reliability. As a general rule, complexity in design should be avoided even at the sacrifice of a certain degree of flexibility of operation. A reliable unit that gathers a reasonably representative sample most of the time is much more desirable than an extremely sophisticated, complex unit that gathers a very representative sample 10 percent of the time, the other 90 percent of the time being spent undergoing some form of repair due to a malfunction associated with its complexity.

It is also desirable that the cost of the equipment be as low as practical both in terms of acquisition as well as operational and maintenance costs. For example, a piece of equipment that requires 100 man-hours to clean after every 24 hours of operation is very undesirable. It is also desirable that the unit be capable of unattended operation and remaining in a standby condition for extended periods of time.

The sampler should be of sturdy construction with a minimum of parts exposed to the sewage or to the highly humid, corrosive atmosphere associated directly with the sewer. It should not be subject to corrosion or the possibility of sample contamination due to its materials of construction. The sample containers should be capable of being easily removed and cleaned; preferably they should be disposable.

For portable automatic wastewater samplers, the list of desirable features is even longer. Harris and Keffer (16) give a number of features of an "ideal" portable sampler, which are based upon sampler comparison studies and over 90,000 hours of field experience.

D.4.2.3 Survey of Commercially Available Equipment

Some types of automatic liquid sampling equipment have been available commercially for quite a while. In the last few years, however, there has been a proliferation of commercial sampling equipment designed for various applications. New companies are being formed and existing companies are adding automatic sampling equipment to their product lines. In addition to their standard product lines, most manufacturers of automatic sampling equipment provide special adaptations of their equipment or custom designs to meet unique requirements of certain customers. Some designs that began in this way have become standard products, and this can be expected to continue.

The products themselves are also rapidly changing. Not only are improvements being made as field experience is gathered with new designs, but attention is also being paid to certain areas that have heretofore been largely ignored. For example, one company is introducing sampling probes that allow the gathering of oil or various other liquids from the flow surface; solid-state electronics are being used more and more in sampler control subsystems; new types of batteries are offering extended life between charges and less weight; and so on. Table D-17 lists the names and addresses of some 54 manufacturers who are known to offer standard lines of automatic wastewater sampling equipment.

An overall matrix, which summarizes the equipment characteristics to facilitate comparisons, is presented in Table D-18. There are several column headings for each sampler model (or class of models). "Gathering Method" identifies the actual method used (mechanical, forced flow, suction lift) and type (peristaltic, vacuum, centrifugal pump, etc.). Depending upon the gathering method employed, the sample flow rate may vary while a sample is being taken, vary with parameters such as lift, etc. Therefore, the "Flow Rate" column typically lists the upper end of the range for a particular piece of equipment, and values significantly lower may be encountered in a field application. "Lift" indicates the maximum vertical distance that is allowed between the sampler intake and the remainder of the unit (or at least its pump, in the case of suction lift devices).

"Line Size" indicates the minimum line diameter of the sampling train. "Sample Type" indicates which type or types of sample the unit (or series) is capable of gathering. Not all types can necessarily be taken by all units in a given model class; e.g., an optional controller may be required to enable taking a TvVc type sample, etc. The "Installation" column is used to indicate if the manufacturer considers the unit to be portable or if it is primarily intended for a fixed installation. "Cost Range" indicates either the approximate cost for a typical unit or the lowest price for a basic model and a higher price reflecting the addition of options (solid-state controller, battery, refrigerator, etc.) that might enhance the utility of the

TABLE D-17
AUTOMATIC WASTEWATER SAMPLER MANUFACTURERS

A & B Enterprises
1711 South 13th Avenue
Omaha, Nebraska 68108

Advanced Instrumentation, Inc.
Box 2226
Santa Cruz, California 95063

T. A. Baldwin Company, Inc.
16760 Schoenborn Street
Sepulveda, California 91343

Bestall-Bean Limited
52 Manley Road North,
[illegible]
Manchester, England [illegible]

BIF Sanitrol
P.O. Box 4
Largo, Florida 33540

Brailsford and Company, Inc.
Milton Road
Rye, New York 10580

Brandywine Valley Sales Co.
20 East Main Street
Honey Brook, Pennsylvania 19344

Chandler Development Company
1732 East Dunne Avenue
Sunnyvale, California [illegible]

Chicago Pump Division
FMC Corporation
1607 FMC Drive
Itasca, Illinois 60143

Collins Products Co.
P.O. Box 382
Livingston, Texas 77351

Environmental Marketing
Associates
3331 Northwest Elmwood Dr.
Corvallis, Oregon 97330

ETS Products
12161 Lackland Road
St. Louis, Missouri 63141

Fluid Kinetics, Inc.
3120 Production Drive
Fairfield, Ohio 45014

Horizon Ecology Company
7435 North Oak Park Drive
Chicago, Illinois 60648

Hydro-Dynamic Sales Co.
41 Hudson Street
Hackensack, New Jersey 07601

Hydragraph Automatic Samplers
450 Ross Street
Lebanon, Oregon 97355

Instrumentation Specialties Co.
Environmental Division
P.O. Box 5347
Lincoln, Nebraska 68505

Kent Cambridge Instrument Co.
73 Spring Street
Ossining, New York 10562

Lakeside Equipment Corp.
1022 East Devon Avenue
Bartlett, Illinois 60103

Manning Environmental Corp.
120 DuBois Street
P.O. Box 1356
Santa Cruz, California 95061

Markland Specialty Eng. Ltd.
Box 145
Etobicoke, Ontario Canada

Nalco Chemical Company
180 N. Michigan Avenue
Chicago, Illinois 60601

[illegible] Corporation
Croton Falls Industrial Complex
Route 22
Croton Falls, New York 10519

N-Con Systems Company
308 Main Street
New Rochelle, New York 10801

[illegible] Company
405 Illinois Avenue
[illegible], Illinois [illegible]

PP Industries, Inc.
P.O. Box 736
Niagara Falls, New York 14302

[illegible] Company, Inc.
[illegible] Clark Drive
[illegible], New York [illegible]

Phipps and Bird, Inc.
303 South 6th Street
Richmond, Virginia 23205

ProTech, Inc.
Roberts Lane
Malvern, Pennsylvania 19355

Quality Control Equipment Co.
P.O. Box 2706
Des Moines, Iowa 50315

Sigmamotor, Inc.
14 Elizabeth Street
Middleport, New York 14105

Sirco Controls Company
8815 Selkirk Street
Vancouver, B.C.

Sonford Products Corporation
100 East Broadway, Box B
St. Paul Park, Minnesota 55071

Testing Machines, Inc.
400 Bayview Avenue
Amityville, New York 11701

[illegible] Corporation
[illegible] South Broadway
Carrollton, Texas [illegible]

Tri-Aid Sciences, Inc.
161 Norris Drive
Rochester, New York 14610

Williams Instrument Co., Inc.
P.O. Box 4365, North Annex
San Fernando, California 91342

Universal Engineered Systems, Inc.
7071 Commerce Circle
Pleasanton, California 94566

TABLE D-18

SAMPLER CHARACTERISTIC SUMMARY MATRIX

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE D-19

SAMPLER CHARACTERISTIC SUMMARY MATRIX (Continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]

device. Finally, the "Power" column is used to indicate whether line current (AC), battery (DC), or other forms of power (e.g., air pressure) are required for the unit to operate.

D.4.2.4 Review of Recent Field Experience

In order to assess the efficacy of both commercially available samplers and custom engineered units in actual field usage, a survey of recent USEPA projects, many of which were in the storm and combined sewer pollution control area, was conducted. None of these projects was undertaken solely to compare or evaluate samplers, but all required determination of water quality. In the following paragraphs, difficulties encountered with various elements of the liquid samplers are described.

The small diameter, low intake velocity probes found in several commercial units were felt to be unable to gather as representative a sample of the flow as could be obtained manually. There were many instances of inlet tube openings being blocked by rags, paper, disposable diapers, and other such debris. Although less a fault of the equipment than an installation practice, there were several instances of intake tubes being flushed over emergency overflow weirs, up onto manhole steps, etc., during periods of high flow and left high and dry and unable to gather any samples when the flow subsided.

There were numerous instances of pre-evacuated bottle samplers losing their vacuum in 24 to 48 hours, resulting in little or no data. Furthermore, personnel find these units with their 24 individual intake tubes virtually impossible to clean in the field. The low suction lifts on many commercial units render some sites inaccessible. In one project, three sites required manual sampling because none of the samplers on hand could meet the 5- to 6-meter lifts required at these sites. There were several instances of sample quantity varying with sewage level as well as with the lift required at the particular site. On at least two occasions, submersible pumps were damaged or completely swept away by heavy debris in the flow.

Within the sampling train itself, line freezing during winter operation was a problem in several projects with instances of up to 60-percent data loss reported. In one project, the intake line was too large, which allowed solids to settle out in it until it ultimately became clogged. There were numerous instances of smaller suction tubes becoming plugged with stringy and large-sized material. A very frequent complaint, applied especially to discrete samplers, was that they gathered inadequate sample volumes for the laboratory analyses required.

On one project, although not directly the fault of the sampling equipment itself, data were lost for 14 storms due to improper sterilization of non-disposable sample bottles.

The control subsystems of commercial units probably came in for more criticism than any other. Comments on automatic starters ranged from poor to unreliable to absolutely inadequate. There were instances where dampness deteriorated electrical contacts and solenoids causing failure of apparently well-insulated parts. The complexity of some electrical systems made them difficult to maintain and repair by field personnel. Inadequate fuses and failures of microswitches, relays, and reed switches were commonly encountered. The minimum time between collection of samples for some commercial units was too long to adequately characterize some rapidly changing flows.

Collected USEPA experience in one region reported by Harris and Keffer (16) involved over 90,000 hours use of some 50 commercial automatic liquid samplers of 15 makes and models. They found that the mean sampler failure rate was approximately 16 percent with a range of 4 to 40 percent among types. They also found that the ability of an experienced team to gather a complete 24-hour composite sample is approximately 80 percent. When one factors in the possibility of mistakes in installation, variations in personnel expertise, excessive changes in lift, surcharging, and winter operation, it is small wonder that projects on which more than 50 to 60 percent of the desired data were successfully gathered using automatic samplers were, until recently, in the minority.

In fairness to present day equipment, it must be pointed out that some of the above cited complaints stem from equipment designs of up to 10 years ago, and many commercial manufacturers, properly benefitting from field experience, have modified or otherwise improved their products' performance. The would-be purchaser of commercial automatic samplers today, however, should keep in mind the design deficiencies that led to the foregoing complaints when selecting a particular unit for his application.

D.4.3 Manual Versus Automatic Sampling

The decision whether to sample manually or use automatic samplers is far from straightforward, and involves many considerations in addition to equipment costs. Experience has indicated that operator training is necessary if manual sampling is to produce reproducible results. Instances have been noted wherein two different operators were asked to obtain a sample at a particular site with no other guidance given. Analyses of samples taken at almost the same instants in time have shown differences exceeding 50 percent. Other work conducted solely to compare manual sampling methods has indicated such discrepancies in results that suspicion must be cast upon manual methods that involve dipping of samples out of raw waste sources and has raised questions regarding the suitability of such manual grab sampling as a yardstick against which to measure other techniques.

The decision to use automatic sampling equipment does not represent the universal answer to water and wastewater characterization, however. For initial characterization studies, proper manual sampling may represent the most economical method of gathering the desired data. It is also prudent from time to time to verify the results of an automatic sampler with manual samples.

In general, manual sampling is indicated when infrequent samples are required from a site, when biological or sediment samples or both are also required from a site, when investigating special incidents (e.g., fish kills, hazardous material spills), where sites simply will not allow the use of automatic devices, for most bacteriological sampling, etc. Manual sampling will often be the method of choice in conducting stream surveys, especially those of relatively short duration where only a single daily grab sample is required from each site. For large rivers, lakes, and estuaries, manual sampling will almost always be required.

Automatic samplers are indicated where frequent sampling is required at a given site, where long-term compositing is desired, where simultaneous sampling at many sites is necessary, etc. Automatic sampling will often be the method of choice for storm-generated discharge studies, for longer period outfall monitoring, for treatment plant efficiency studies, where 24-hour composite samples are required, and so on.

Typically, the wide spectrum of 208 agency monitoring activities will require a capability for both manual and automatic sampling, and so the question is not which capability to obtain but when to use each. The answer should be determined in the design of each survey, using the above information as guidance.

D.4.4 Sampling Field Procedures

D.4.4.1 Manual Sampling Procedures

The preferred method of gathering manual samples from a raw waste stream is to use a pump to actually extract the fluid and tubing of appropriate size to transport it to the sample container. Pump and tubing sizes should be such that effective collection and transport of all suspended solids of interest is ensured. Both small, flexible impeller centrifugal pumps and progressive cavity screw pumps have been successfully used with good repeatability of results. It should be noted, however, that the collection of flow proportional or sequential composite samples can become quite tedious if performed manually at the sampling site. Locate the intake at approximately the three-quarters depth point (i.e., one-fourth of the way up from the bottom) and point it upstream into the flow. Adjust the pump speed until intake velocity approximately equals the mean flow velocity (obtained from a flow-measuring device or current meter) and, after about 60 seconds, direct the stream into the sample container. Avoid using an intake screen unless absolutely necessary.

When manually sampling natural streams, use a depth-integrating sampler at the center of the stream if the flow is laterally homogeneous. Check the site for this by occasionally taking samples from the quarter points and comparing results. If significant differences are found, either choose another site or take a number (5 to 20 depending upon stream width) of depth integrated samples along a transect perpendicular to the flow. Based on the results, choose the minimum number of transverse stations that will yield acceptable results.

Depth integrating samplers for use in more swiftly running streams are relatively heavy, and so some type of hoist or winch is normally used to facilitate handling. These can be mounted on boats for river and estuary cruises, on trucks or trollies for bridge sampling, etc. Contact the nearest USGS field office for more information on availability and use of different depth integrating samplers.

Samples may be manually gathered at a given depth in the water column by using a Juday bottle or one of its modifications (e.g., Kemmerer, Van Dorn). This type is essentially a cylinder with stoppers that leave the ends open while the sampler is being lowered to allow free passage of water through the cylinder. When the desired depth is reached (as determined by markings on the line, for instance) a messenger is sent down the line and causes the stoppers to close the cylinder, which is then raised and the sample transferred to its container. These devices can be used to approximate depth integration through the water column, to investigate stratification in lakes, or wherever a sample from a particular depth is desired. When using such devices from bridges, take precautions so that the messenger, when dropped from the height of the bridge, does not batter and ruin the triggers that release the stoppers. One simple way to avoid this is to support the messenger a few feet above the sampler with a string and release it when the desired depth is reached.

If vertical concentration gradients are not severe, a single grab sample will suffice. It is recommended that a container smaller in volume than the desired total sample volume be used, and that the required sample volume be obtained by repeated dippings at one minute intervals. Rinse the container two or three times in the water to be sampled prior to taking the first aliquot. Comparison of the results between depth integrated and simple grab samples will indicate when the latter technique will suffice.

For reproducibility of manual sampling results, operator training is absolutely essential; 208 agencies can ill afford to entrust this task to well-intentioned but untrained staff or volunteers. Also, it is time that we forget about using a beer can nailed to a stick as a sample gathering device. All in all, the manual pumping sampler described earlier in this section will produce the most reproducible results, and its use is recommended whenever feasible. One subject that should also be touched on briefly is manual compositing according to flow records. Given a series of discrete samples of equal volume taken at regular time intervals and a flow record, the question is what size aliquot should be taken from each discrete sample container to form the flow proportional composite sample? Recall from Section D.4.1 that this can be done in one of two ways: either extract an aliquot volume that is proportional to the instantaneous flow rate at the time the discrete sample was taken, or extract an aliquot volume that is proportional to the total discharge that has occurred since the last discrete sample was taken. The formula used for this can be written as:

$$a_i = f_i \, V_c / \Sigma f_i$$

where: a_i = aliquot volume to be extracted from the i th discrete sample, i.e., the one taken at time t_i

i = index indicating the order in which the discrete samples were taken, $1 \leq i \leq n$

f_i = flow variable; either the flow rate when the i-th discrete sample was taken (q_i) or the total discharge that has occurred since the (i-1)-th sample was taken ($\Delta Q_i = Q_i - Q_{i-1}$)

V_c = composite sample volume desired

n = number of discrete samples taken

The desired composite sample volume is determined based on the requirements for the analyses to be conducted. The subtle problem is that one does not have complete freedom in selecting V_c because of the fixed discrete sample volume (V_d), and the entire sequential discrete series may be wasted if this is not recognized, because there might not be enough sample in one bottle to fulfill its aliquot requirements. This is best illustrated by an example (see Table D-19). Note that if steps 3 and 4 had not been carried out, when the operator came to bottle number 5 he would not have been able to continue, since he would be 250 mℓ short. This has happened. Also, it is incorrect to use leftover liquid from the adjacent discrete samples to make up the deficit (which has also occurred).

In actuality, one can compute the maximum composite sample volume that can be formed from a series of discrete samples. The formula is

$$(V_c)_{max} = V_d \, \Sigma f_i/(f_i)_{max}$$

If this quantity is greater than the amount desired, the formula given earlier for determining aliquot volume can be used. If not, the aliquot size should be computed from

$$a_i = f_i \, V_d/(f_i)_{max}$$

This will be illustrated by a second example, shown in Table D-20. Since the available composite sample is nearly half a liter less than was desired, a new decision on how to allocate the available volume must be made.

Example III (Table D-21) is included to indicate how to manually prepare a time-constant, volume-proportional-to-discharge-since-last-sample-was-taken composite when a record of flow rate rather than discharge is available. The results of Examples II and III agree because the same flow function (q=5,000 sin $\pi t/8$) was used in each case and the trapezoidal integration scheme worked well.

The details for manually preparing a time-constant, volume-proportional-to-instantaneous-flow-rate composite sample using the flow rate record given in Example III will not be presented (a_i=191, 354, 462, 500, 462, 354, 191, 0; Σa_i=2,514 mℓ), but it is of interest to contrast the measured concentration of a constituent of interest obtained by this method as opposed to the method of Example II. For this purpose, assume that the constituent behavior is a

TABLE D-19
MANUAL COMPOSITE SAMPLE EXAMPLE I

Example: Manually preparing a time-constant, volume-proportional-to-instantaneous-flow-rate composite sample.

Given: A 500 mℓ discrete sample was taken at the end of each hour over an 8-hour shift. A 2-liter composite is desired. A recording of flow rate is available.

Sample No. (i)	q_i	a_i	a_ix500/750
1	300	47	31
2	600	94	63
3	1,200	188	125
4	2,400	375	250
5	4,800	750	500
6	2,000	312	208
7	1,000	156	104
8	500	78	52
Σq_i =	12,800	2,000	1,333

Steps:

1. Enter q_i from record and sum.
2. Calculate $a_i = q_i V_c / \Sigma q_i = 2000 q_i / 12,800$.
3. Check to see if maximum a_i exceeds discrete sample volume.
4. Compute new aliquot volume = a_ix500/750.

TABLE D-20
MANUAL COMPOSITE SAMPLE EXAMPLE II

Example: Manually preparing a time-constant, volume-proportional-to-discharge-since-last-sample-was-taken composite.

Given: A 500-mℓ discrete sample was taken at the end of each hour over an 8-hour shift. A 3-liter composite is desired. A recording of totalized flow is available.

Sample No. (i)	Q_i	ΔQ_i	a_i
0	0	-	-
1	969	969	99
2	3,729	2,760	284
3	7,860	4,130	424
4	12,732	4,873	500
5	17,605	4,873	500
6	21,736	4,130	424
7	24,496	2,760	284
8	25,465	969	99
	$\Sigma\Delta Q_i$ =	25,464	2,614

Steps:

1. Enter Q_i from record and calculate $\Delta Q_i = Q_i - Q_{i-1}$.
2. Calculate $(V_c)_{max}$ = (500) (25,464)/4,873 = 2,614 mℓ.
3. Since $(V_c)_{max}$ is less than desired, calculate aliquot size from a_i = 500 ΔQ_i/4,873.

TABLE D-21
MANUAL COMPOSITE SAMPLE EXAMPLE III

Example: Manually preparing a time-constant, volume-proportional-to-discharge-since-last-sample-was-taken composite.

Given: A 500-ml discrete sample was taken at the end of each hour over an 8-hour shift. A 3-liter composite is desired. A recording of flow rate is available.

Sample No. (i)	q_i	ΔQ_i	v_i
0	0	-	-
1	1,913	957	99
2	3,536	2,725	283
3	4,619	4,078	424
4	5,000	4,810	500
5	4,619	4,810	500
6	3,536	4,078	424
7	1,913	2,725	283
8	0	957	99
	$\Sigma\Delta Q_i$ =	25,140	2,612

Steps:

1. Enter q_i from record and use trapezoidal rule to calculate $\Delta Q_i = (q_i + q_{i-1})/2$ (another integration scheme could be used if warranted).
2. Calculate $(V_c)_{max} = (500)\ (25,140)/4,810 = 2,613$
3. Calculate $v_i = 500\ \Delta Q_i/4,810$

simple linear decay (i.e., conc.=9-t). The true concentration in the flow rate proportional sample would be 5.0 (assuming the discrete samples from which the composite was formed were 100 percent representative). The corresponding true concentration of the discharge proportional composite (Example II) would be 4.5, a difference of around 10 percent due solely to the method of compositing.

The possible importance of sediment oxygen demand (SOD) measurements to 208 agency plans is well illustrated by Butts (17) who noted, as a result of an extensive SOD study, that "... it is doubtful that the aquatic ecology of the (Illinois) waterway can be measurably enhanced solely by achieving current water quality standards." The subject of SOD measurement remains somewhat controversial, but it is recommended that determinations be made in situ rather than in the laboratory. Ascertaining the relationship between SOD rates and DO content of the overlying waters is better accomplished by performing in situ measurements. This can be done, for example, by setting a bell-shaped shallow cover over the spot on the bottom where the measurement is to be made, circulating the water within this "sampler" with a small pump, and measuring the change in DO with time.

The design of an in-situ SOD measuring device developed by the Illinois State Water Survey is described by Butts (17), who also reports favorably on its use. The cover was made from a 14-inch-diameter by 24-inch-long steel pipe split longitudinally in half. End plates were welded on, and angle iron was welded around the lower edge to act as cutting edges and seating flanges. Fittings for raising and lowering the device, two hose attachments to allow connection of a pump for water circulation, and a split collar to hold the DO/temperature probe were also welded in place. The "sampler" covered a flat bottom area of about 0.2 square meter (336 sq in.), and the total volume of water within the system was around 31 liters. The device is handled with a USGS bridge winch adapted for use on a boat.

D.1.4.2 Automatic Sampling Procedures

When using automatic samplers, the greatest problem comes in mounting the intake. Screened intakes should be used in waters containing large solids, trash, or debris to prevent clogging. Screen openings should be slightly smaller than the smallest opening in the sampling train. More and more commercial devices are now provided with intake screens by their manufacturers. When using these, the end of the intake hose should be approximately at the center of the screen. If intake screens are not provided with the samples, they can be fabricated quite simply by drilling a large number of appropriately sized holes in a piece of plastic pipe, cementing on end covers, and drilling out one end to accept the sample tube and fastening it with a hose clamp and fitting. Clear plastic is recommended to facilitate inspection. A typical size for an intake screen to accommodate a 3/8 inch ID tube is approximately 1.5 to 2 inches in diameter by 6 to 10 inches long. Hole diameters could be 1/4 inch if the rest of the sampling train is larger.

The flexible plastic intake tubing commonly used in most commercial automatic samplers will require some protection in many installations, or wear from particles in the flow and damage from debris will necessitate frequent replacement. Flexible electrical conduit and reinforced garden hose have been successfully used in this regard. Even with such protection, it is recommended that sample intake lines be trenched in where they run over earthen surfaces.

One of the most challenging sample intake mounting problems is in a natural, wet weather stream. If the intake is allowed to rest on the bottom where it could obtain samples at very low flows and, hence, more readily determine first flush effects, there is a possibility that flow fields around the intake may induce scour and cause artificially high solids readings. Mounting the intake well above the bottom obviates this problem but prevents acquiring samples of very low flow. The best compromise seems to be to mount the intake horizontally, at right angles to the flow, in the middle of the stream and with its lowest surface around 2 inches above the bottom (higher if significant bedload depths are anticipated). The stream bottom at this point should be reasonably flat and free of stones or other flow-altering obstructions upstream of the intake. For cobble-strewn bottoms, follow the above procedure but measure from a sheet of plywood resting on the stones.

To anchor the sample intake to the bottom, use screw augers or metal rods driven well into the soil. Simple hose clamps can be used to affix the intake screen to these supports.

For continuously flowing natural streams, similar considerations pertain. The main difference will be in the vertical location of the intake. In the absence of other factors, mount the intake near the low flow mid-depth. If stream depth allows, the intake should be mounted with its center line vertical, and suction taken from the bottom. In this configuration, a single mounting rod can be used. It should be located to one side of the intake (never in front of it).

The foregoing has been written with smaller streams, typical of those that would be encountered in an urban runoff study, in mind. As indicated earlier in this section, it is not expected that automatic samplers will find wide use in river monitoring.

In man-made channels and conduits, there is no longer a concern for bottom scour. For those carrying intermittent flows, the intake screen can be allowed to rest on the bottom unless significant bedload depths are anticipated. Where large debris is likely to be encountered, a spring-loaded intake screen mounting should be considered to help prevent destruction. It is a fairly common practice to simply let the intake screen trail downstream by its tubing. In very low or no-flow periods it will rest on the invert and, during higher flows, hydrodynamic forces will tend to lift it up. The chief objection to this practice is that probes facing downstream do not gather representative solids due to momentum effects. Data on the degree of under-representation caused by this practice are virtually nonexistent, however. Use this practice as a last resort.

Where the flow is continuous (but variable), position the intake screen near the low flow mid-depth. As opposed to natural streams, however, in many man-made conduits it will be more convenient to dangle the intake from above with the suction tube pointing down. Although the vertically up orientation is preferable, this practice is also acceptable. The chief disadvantage of "dangling" approaches to intake mounting is that you never really know where the intake is. Be certain that there is no possibility of full flow positioning the intake where it could be left "high and dry" as the flow recedes. Manhole benches, steps, weirs, and the like have taken their toll in careless intake installations.

For the (rare) case where relatively steady flow is anticipated in either natural or man-made channels, position the intake at about the three-quarter depth point. If two automatic sampling devices are used for redundancy at a critical site, position one intake at the eight-tenths depth point and one at the four-tenths depth point. Shelley (18) discusses the rationale for sample intake location in some detail and presents designs for maintaining intakes at a constant percentage of depth in variable flows, noninvasive intakes, etc.

All of the foregoing has been written primarily with suction lift intakes in mind, but similar considerations apply if forced-flow devices are used. For samplers employing mechanical gathering methods, follow the manufacturer's directions.

Mounting the main body of the automatic sampler is rather straightforward; follow the manufacturer's directions. Keep the lift as short as possible commensurate with the likelihood of submergence. If excess sample tubing exists, cut it off. Do not simply coil it out of the way, thinking that the extra length might be useful at the next installation.

After setting up the controls and power subsystem according to the operator's manual for the particular sampler being used, manually cycle it a few times and measure the quantity of sample actually being taken. This is especially important where fixed aliquot volume composite samples are to be collected. Verify sample volume gathered on each site visit. Partial plugging, intake blockage, or other occurrences that might not be immediately obvious can affect the sample quantity in most designs. Also, use a stopwatch to record the time that it takes to gather the sample and verify this on subsequent visits. For battery-operated units, frequent voltage checks are in order until service life can be established for the installation. Manufacturers are not noted to be conservative in estimating battery life, and it will be affected by a number of factors such as sample lift, temperature, etc. Always inspect the sample intake at each visit.

For operation in very cold weather, a heated enclosure for the sampler body will be required. Sample lines should be wrapped with heater tape and insulated -- large plastic trash bags work well for this. Check for possible ice buildup at each visit. Should frozen (or partially frozen) samples be encountered, do not discard them, but immediately enter the facts in the field log and also report the condition to the analytical laboratory when the samples are delivered.

Maintenance and troubleshooting of automatic samplers are so design-dependent that little general guidance can be given other than to follow manufacturer's instructions and recognize the importance of these activities in contributing to project success. However, one word of caution pertaining to suction lift samplers using peristaltic pumps must be made. Some of these pump designs require that the tubing be lubricated. This must be done or tube life will be considerably shortened; failures after less than 2 hours of operation have been reported for some designs when inadequate lubrication was applied. With care and consideration, most automatic samplers can be made to work reasonably well; with carelessness and disregard, almost none will.

D.4.5 Sample Quantity, Preservation, and Handling

Since the required sample volume is dependent upon the type and number of parameters to be analyzed for and the instrumentation and methods to be employed in the analysis at the laboratory, the laboratory analyst is the best person to specify the quantity needed. A preliminary estimate of sample volume can be obtained as follows. Determine the parameters to be analyzed for and, from the Parameter Handbook, obtain the sample volume required for each analysis. Sum these to obtain the minimum volume, and increase this amount as necessary to allow for spillage, mistakes, sample splitting, and for analytical laboratory quality control purposes. In the absence of better information, doubling the minimum volume should be adequate.

Having collected a representative sample of the fluid mixture in question, there remains the problem of sample preservation and analysis. It is a practical impossibility either to perform instant analyses of the sample on the spot or to completely and unequivocally preserve it for subsequent examination. Preservation methods are intended to retard biological action, retard hydrolysis of chemical compounds and complexes, and reduce volatility of constituents. They are generally limited to pH control, chemical addition, refrigeration, and freezing. The USEPA (19) has compiled a list of recommendations for preservation of samples according to the measurement analysis to be performed. In order to provide an overview for some common parameters, this list has been reproduced here as Table D-22. For other parameters and program design, reference should be made to the Parameter Handbook.

Proper sample handling is also essential to obtaining successful results from any monitoring program. A few general guidelines are given below.

1. Each sample container must have a designation, normally a number, that uniquely distinguishes it from all other samples in the survey.

TABLE D-22
RECOMMENDATIONS FOR PRESERVATION OF SAMPLES ACCORDING TO MEASUREMENT[1]

[illegible]

2. When frequent sampling over a long time period is involved, consideration should be given to incorporating a temporal indication as a part of the sample identification number; e.g., the number of the week in a year, the last two digits of the year, etc. The temptation to code too much information about the sample into its identification number must be resisted, however, or else the risk of mixups due to unauthorized abbreviations becomes too great.

3. Consideration should be given to the use of preprinted, sticky-back labels in many instances. Be certain, however, that they are waterproof. Rubberband and tie-on tags have also been used successfully.

4. The use of color-coded labels has been successful where sample splitting or different preservation techniques are employed. In the latter case, for example, a green label could indicate that nitric acid had been added and that, therefore, an analyst could obtain aliquots from this sample for metal analyses, etc.

5. Where possible, the type of sample, date, and any preservatives added should be written on the sample label prior to collecting the sample in the field. The time of day should be added when the sample is collected. Additional information should be noted in the field notebook and on supplemental forms where used.

6. The foregoing should be observed in addition to any chain-of-custody procedures that are involved. See (20) for USEPA recommendations for a chain-of-custody program.

The proper cleaning of all equipment used in the sampling of wastewater is essential to ensuring valid results from laboratory analyses. Cleaning protocols should be developed for all sampling equipment early in the design of the monitoring program. Here, also, the laboratory analyst should be consulted, both to ensure that the procedures and techniques are adequate as well as to avoid including practices that are not warranted in view of the analyses to be performed. The possibility of the container affecting the sample analyses should be checked periodically. Distilled or demineralized water should be placed in a typical container for a period of time similar to that of a normal sample. Then the particular constituent of interest should be measured in the water from this blank. Also, checks for sample adsorption on the container should be made by placing a known amount of a particular constituent in a typical container. After a specified holding time, analyses should be made to determine if any of the material was adsorbed into the container or changed in any other manner. These checks should be done after sample bottles have been used for a series of samples. In this way the cleaning techniques used can be tested for thoroughness.

The use of blanks and spikes just mentioned brings up the subject of quality control in general. Although outside the scope of this Appendix, each 208 agency must have a viable quality assurance program. The USEPA (21, 22) has published minimal requirements for a water quality assurance program and a handbook for analytical quality control in the laboratory. The recommendations in these two references should be followed by all 208 agencies.

D.4.6 Sampling Accumulated Roadway Material

Accumulated roadway material may represent a significant source of pollution during storm-generated discharges in urban areas. In order to quantify this source, provide inputs for models, determine if better urban housekeeping practices would produce commensurate water quality improvements, etc., sampling of accumulated roadway material will be required. The following discussion is abstracted from Wullschleger et al. (7).

Samples of materials deposited on roadways are collected using a combination of sweeping, vacuuming, and water flushing techniques. Each sample will consist of three fractions: litter, dust and dirt, and water flush. The particulate materials collected by sweeping and vacuuming are separated on the basis of particle size into a litter fraction and dust and dirt fraction. The litter fraction consists of that portion of the particulates retained by a U.S.A. No. 6 sieve (i.e., greater than 3.35 mm in diameter). This fraction is usually composed of stones, gravels, wood fragments, and other larger sized materials in addition to bottles, cans, paper production, etc., which are normally thought of as litter. The dust and dirt fraction will contain particulates smaller than 3.35 mm in diameter. The water flush fraction contains those components of the dust and dirt fraction which were not picked up at high efficiencies by the sweeping and vacuuming techniques. The flush plus the dust and dirt constitute a total dust and dirt fraction which is the major source of water pollutants found in runoff from urban roadways.

If a physical and chemical description of the street surface contaminants is needed, the sample should be collected by hand sweeping, followed by flushing. All of the dry solid material collected from the test area should be placed in clean containers and shipped back to the laboratory. There it should be air dried thoroughly and sealed for storage until analyzed. All of the flushed material should be measured for volume, but only a portion of it need be retained for analysis. The liquid sample should be stored in clean containers (glass, if pesticide analyses are to be made) and cooled to <4°C if possible. The analyses of the liquid fraction should be made as soon as possible after collection. To reduce the number of chemical analyses required, the dry and liquid samples can be combined on an equal sample area basis before the analyses are performed.

If only physical loading information (such as kg (lb) of solids per curb km (mile)) is needed, hand sweeping is probably sufficient. In most cases, the additional quantity of material that can be obtained by subsequent vacuuming and/or flushing is insignificant. If information regarding particle size distribution is required, then the sample should be collected using a combination of hand sweeping and dry vacuuming. The vacuum is more efficient in removing the fine particles which are needed for size distribution analyses. If size distribution of the solids in the wet phase is needed, then flushing will also be required.

The basic procedures for the collection of samples are:

Hand sweeping - Hand sweeping for dry solids collection should utilize a standard stiff-bristled push broom. The sweeping pattern should be from the center of street or from one edge of the test area towards the gutter or opposite side of the test area. After concentrating the material along this edge, the sample should be collected, using a whisk broom and dustpan.

Vacuuming - Vacuuming the test area usually removes more smaller-sized particles than is possible by only using sweeping techniques. The vacuuming pattern should approximate the pattern described for hand sweeping. An industrial wet/dry "shop" vacuum cleaner with a 5-7.6 cm (2 in. to 3 in.) diameter hose is recommended. Other types of units, ranging from small household vacuums to large motorized vacuum sweepers, may also be satisfactory, depending on the size of the test area.

Flushing - The test area can be flushed with water after hand sweeping to remove soluble films and other nonsweepable material. The materials removed with this method more closely resemble those which are removed by a runoff event. The test area is first slightly wetted to soften and facilitate removal of soluble materials. It is then flushed with a stream of water from a garden hose and spray nozzle connected to a fire hydrant or other water supply. Begin at the road crown and flush toward the edge. The downslope gutter is dammed with sandbags to create a collection area. A small vacuum collector is used before an industrial wet/dry vacuum cleaner to remove the sample water from the collection area. All water and contaminants are collected using this vacuum-operated collector trap. This is an air-tight box or drum with a capacity of several gallons to several hundreds of gallons (depending upon specific test procedures), outfitted to function as a "trap" in a vacuum line. The inlet hose of the collector trap has a pickup nozzle on the open end. The outlet hose of the collector trap is connected to an industrial shop vacuum.

The vacuum cleaner used for collection of roadway particulates consists of a pick-up head attached to a 38ℓ (10 gal) canister on the top of which is mounted an exhaust motor. Exhaust ports from the canister leading to the motor are covered by a filter bag to retain solids picked up during the vacuuming operations. Since the finer particles found on roadways are relatively more heavily laden with water pollutants, experiments have been performed to determine the retention of smaller-sized particles by the filter bag. Recoveries of 99, 93, and 94 percent were obtained using a new filter bag with each sampling run. These tests indicate satisfactory retention of fine particulates by the filter bags as well as quantitative removal and recovery of vacuumed particles from the canister walls and bags.

The water flush procedure has also been tested in the field. It was found that a roadway area of 92 sq m (1000 sq ft) could be thoroughly flushed with about 95ℓ (25 gal) of water. In most cases, over 50 percent of the applied flush was recovered by vacuuming of the impounded waver along the curb.

A specific stepwise sampling procedure for the collection of street surface contaminants is given below.

1. Select a roadway sampling site 30.48 continuous curb meters (100 ft) or more. The street surface and curbing should be in relatively good condition. Mark the limits of the sampling length selected.

2. Rake and/or brush along the curb for 3.0 or 4.6m (10 or 15 ft) from the limit markings *away* from the section to be sampled.

3. Knock the brush clean. Rake and/or brush from the higher elevation limit. Shovel bulk litter plus swept dust and dirt into a clean galvanized garbage can.

4. Vacuum along the entire curb length of the roadway sampling site out to a distance of four to five feet from the curb. Three vacuumings of the site should be carried out to collect the dust and dirt sample fractions. Two vacuum cleaners are

used simultaneously to speed up the operation with particular attention at the litter pickup point.

5. Position several sand bags at the curb of the lower limit of the sampling area to impound the flush water.

6. Place the nozzle of a dual motor shop vacuum at a low point in front of the sand bags so as to suck water into a 208ℓ (55-gal) drum.

7. Place the intake hose from a rotary screw pump into a 208ℓ (55-gal) drum filled with water and begin flushing the roadway using the garden hose.

8. Flush the entire roadway surface area toward the curb and finish by flushing the gutter toward the sand bags.

9. Approximately 57 to 95ℓ (15 to 25 gal) of water are required to flush 56-93 sq m (600-1000 sq ft) of roadway. Generally greater than 50 percent of the flush water applied is recovered by the vacuum.

10. Take out the filter bags and shake well into garbage can with bulk material. Save the bags.

11. Empty vacuum canisters into garbage can. Brush canisters well.

12. Take combined litter and dust and dirt in garbage can and the flush fraction to the laboratory. Other equipment may proceed to next sampling site.

Sampling sites should be chosen to represent the range of conditions that occur in the area. Important variables may include land use, average daily traffic, type of adjacent landscaping, and street surface material. It is recommended that at least a single complete analysis be made for each land use area, with total solids analyses being made on samples representing other identified variables. If several sampling sites are established in each land use area, a portion of each sample could be combined for complete composite chemical analysis representing that land use.

For one 12-month field study, seven area roadways were chosen based primarily upon the range of average daily traffic levels and road use categories encompassed. Other factors considered in the roadway selections were speed limit and roadway surface material. Satisfactory condition of the street surface and a sufficient length of curb against which the sample could be deposited and collected were important factors in selection of the specific sampling sites on the area roadways chosen.

In general, the following information should be collected for a sampling site: sampling location; date; local land use; parking restrictions; traffic characteristics; composition, type and condition of the street, gutter, and curb; the size of the test area; and a description of the adjoining area. Photographs of the area are often valuable. Data concerning the cleaning frequency, the date of the last recorded cleaning, and the recent rainfall history should also be obtained for each test area.

If the selected study area is subject to vehicular traffic, it will be necessary to establish some type of traffic control for the protection of the field workers. Flagmen and traffic cones are probably a minimum precaution which should be used in all areas.

The type of study area (street surface, parking lots, or other large surfaces) and sampling objectives will determine the size of sampling area. A typical secondary street can usually be sampled using a single test area of about 93 sq m, 7.6m x 12.2m (1000 sq ft, 25 x 40 ft). Large paved surfaces may be better sampled using several smaller test areas (0.9 sq m (10 sq ft)) and averaging the results. Experimental design procedures should be incorporated to determine the necessary types of study areas to sample to satisfy specific study objectives.

As with the selection of the study area, the frequency of sampling will depend on the objectives of the sampling program. For one 12-month field study, a schedule was set up early in the program such that the roadways were sampled during several seasons of the year in order that seasonal effects on pollutant deposition rates might be studied. However, during the winter season, freezing conditions prevented the collection of some of the flush fractions.

Sampling periods were scheduled to begin on a Monday and end one week later on the following Monday. Sample collections were planned to be carried out in the following manner:

1. An initial sample was obtained by cleaning the roadway surface and quantitative collection of materials initially found on the site. No measurements of traffic were taken to correspond with the initial sample; however, records of precipitation and dates of the most recent antecedent cleaning of the roadway surfaces were maintained throughout the 12-month field study.

2. The site was sampled a second time after an accumulation period of approximately 24 hours during which time a measured volume of traffic passed the roadway site. As many as four samples having a one-day accumulation period were taken during the remainder of the week. Traffic counts were taken with each one-day sample.

3. The final sample of the period was gathered following the weekend. Ideally then, a sampling period consisted of an initial sample, four one-day samples, and a weekend sample with traffic data for all samples except the initial one.

4. Precipitation frequently interrupted the planned pattern of the sampling periods. Samples were gathered after rainstorms in a few cases; however, it was felt that such samples would be atypical; and, therefore, collections after runoff events were

abandoned early in the program. The roadway site was cleaned as soon as convenient after precipitation had ceased and a new sample accumulation period begun. Sampling periods were extended in some instances in order to make up for loss of samples due to precipitation.

Experimental design procedures should be incorporated to determine the required sampling frequency and sample numbers to satisfy specific study objectives. The published results of previous sampling programs may be useful in this design process.

D.5 Cost Estimation

It is difficult to provide precise program cost information, since costs are dependent upon so many program and locality related factors, e.g., institutional setting and accounting procedures, area complexities and program size, opportunity free labor, etc. This section presents a methodology for cost estimation for any given program, some "ball park" rules of thumb for preliminary rough cut costing, and some specific examples. The costing methodology is divided into six steps:

1. Estimate Instrumentation Costs
2. Estimate Related Equipment Costs
3. Estimate Manpower Costs
4. Estimate Field Operations Costs
5. Estimate Laboratory Analysis Costs
6. Estimate Data Analysis and Reporting Costs

These will be discussed in turn. Note that modeling costs are not included.

D.5.1 Instrumentation Costs

Instrumentation costs were discussed in Section D.3 and will only be summarized here. These costs represent capital acquisition costs for the most part, and amortization schudules will be a matter of local accounting procedures and discretion. Resist the temptation to lower apparent program costs by using long amortization periods, especially for equipment used in storm-generated discharge studies. Such hostile flows take a great instrumentation toll, and one or two years life is much more typical than ten or twenty.

For flow measurement, the types and numbers of primary and secondary devices must be determined. These are multiplied by the cost of each to arrive at the total dollars required. Make an allowance for spare parts for secondary devices (say 10% in the absence of more specific information). Consider the purchase of at least one complete extra unit to allow for quick field fixes. Instrument breakdown is most likely to occur during important data collection periods, and record interruptions should be as brief as possible.

Langbein and Harbeck (23) reported that a sample of four USGS districts yielded the following costs (in 1972 dollars) for flow-gaging stations: $5K to $10K for installation of an indefinite-term full-record station; $2.5K to $4K for installation of a short-term full-record station; station operating costs of $0.8K to $1.3K per year; office costs for processing the record of $0.5K to $1.3K per year. For partial-record stations, costs as a percentage of full-record stations were stated as: 5 percent for low flow only; 15 to 20 percent for crest stage record; and up to 50 percent for a flood hydrogram. They also noted that there could be extremely large variations outside of these nominal ranges.

In the absence of better information, it is suggested that $10K be budgeted for each urban flow measurement site for the acquisition and installation of a primary flow measurement device. Allow $2K each for the secondary device. The former number takes into account that some sites will allow relatively inexpensive portable devices to be used, while others may require considerable modification, e.g., installation of a below ground metering vault. The desirability of using existing USGS gaging sites where feasible is obvious.

Where possible, try to use existing meteorological instrumentation operated by others. One notable exception will be raingages. They typically cost less than $400 each; recorders may add another $500-$1,000 each. Give serious consideration to the use of leased telephone lines to provide rainfall indication back to a central location. The cost is nominal, and the information is invaluable in crew dispatching and operations. At least one raingage per catchment will be required.

For automatic samplers, the number and types must be determined. For storm-generated discharge sampling, the bulk of the commercially available devices will not be suitable without some modification. Most manufacturers will do this, but it adds cost. Between $2K and $4K should be allowed for each unit. Allow 10 percent for spares and purchase at least one complete extra unit. Also give consideration to installing two separate automatic samplers at critical sites for redundancy. If both function flawlessly, the extra sample quantity won't hurt, and the likelihood of missing a critical storm event is considerably diminished. Manual sampling equipment must be provided to each field crew. Allow two sets for each crew and plan on $100 for each set.

D.5.2 Related Equipment Costs

Shelters will be required for monitoring instrumentation at most sites. Costs can range from under $300 for a metal garden shed to well over $2K if concrete slabs and heavy fencing are required. Consideration should be given to ease of moving instrumentation from site to site; transportable (i.e., trailer) shelters have been used successfully in this regard. For some installations, e.g., one with a large mechanically refrigerated sampler, AC power will be required, and the expense of running electrical lines should be included as part of the overall station cost. Such costs may not be insignificant; $6.4K was spent just to get power to one 208 stormwater monitoring site in Illinois. Site preparation costs should not be capitalized.

Other related equipment that will be required includes small tools, personnel safety and protective gear (e.g., waders, hard hats, respirators, harnesses, etc.), and miscellaneous field hardware. These may or may not be already available. As a very rough estimate, allow 2 percent to 5 percent of the total instrumentation acquisition cost for this purpose. Do not capitalize them.

Other related equipment includes vehicles (automobiles, vans, trucks, etc.), boats, motors, generators, pumps, and the like. These are capital equipment items but, because of their multiplicity of uses, they should probably not be fully charged to a 208 program alone. In the event that the local 208 agency does not have such equipment at its disposal, consideration should be given to leasing rather than purchase. Lease rates vary with locality, but for longer term rentals, i.e., months, not days, rates can be quite reasonable. For mobility of field crews, consideration should be given to leasing extra vehicles during periods of intense activity. Of course all leasing costs should be directly charged to the monitoring program.

D.5.3 Manpower Costs

The manpower costs associated with a 208 monitoring program will vary tremendously from agency to agency, depending upon the size of the program (and hence the number and skill mix of personnel required) as well as local wage scales (including fringe benefits) and accounting practices (application rates for overhead and general and administrative expenses). Therefore, skill levels here will be indicated by estimating equivalent federal government service ratings. Salaries can be adjusted up or down to suit local conditions, and burdens can be applied according to local accounting practices. Table D-23 indicates the types of talent that a 208 program may require.

As an example of the use of Table D-23 to estimate manpower requirements, consider the following. It is desired to conduct one intensive survey per month for a one-year period. The objective of these intensive surveys is to provide information for waste load allocation studies. The basic unit manpower for the estimates made here consist of a field party chief, three qualified technicians, a chemist, a microbiologist, and a biologist. It is assumed that the minimum sampling period would be 5 consecutive days. The

TABLE D-23
TALENT REQUIREMENTS

Skill Area	Federal GS Rating	Annual Pay Rate
Environmental Engineer (1)	GS 13-14	$23K to $35K
Sanitary Engineer	GS 11-12	$16K to $25K
Hydrologist	GS 9-11	$13K to $21K
Chemical Engineer	GS 9-11	$13K to $21K
Chemist	GS 11-13	$16K to $30K
Oceanographer (2)	GS 11-12	$16K to $25K
Biologist	GS 9-12	$13K to $25K
Limnologist (3)	GS 9-11	$13K to $21K
Field Technicians	GS 3-6	$7K to $13K
Lab Technicians	GS 5-7	$9K to $14K
Clerical	GS 2-4	$6K to $10K

NOTES:

1. Assumed to be responsible for overall monitoring program.
2. Required for estuarine or near coastal studies.
3. Required for lake surveys.

basic intensive survey unit manpower estimates are shown in Table D-24. Using the salary figures from Table D-23 as a guide, the direct labor costs for one intensive survey are as follows: Field Party Chief, $26K x 3.75 MW = $1.9K; Chemist, $18K x 16 MW = $5.5K; Biologist, $16K x 5 MW = $1.5K; Field Technicians, $9K x 5 MW = $0.9K; Lab Technicians, $11K x 3.25 MW = $0.7K; Typist $7K x 1 MW = $0.1K. Thus, the total salary requirements for one intensive survey would be approximately $10.6K.

Of course it must be kept in mind that not all personnel time can be utilized at 100 percent efficiency due to a number of reasons (e.g., in runoff studies the field crews have to be paid whether it rains or not), and so a better procedure for budget estimation is to calculate annual salary costs for all required personnel rather than on a work unit basis. One last comment on manpower costs deals with the actual hours worked while in the field. Twelve hour (or longer) days are the rule rather than the exception, and extra compensation for this overtime must be allowed for in arriving at total manpower costs. Non-professional (i.e., non-exempt) personnel must be paid in accordance with applicable wage/hour laws (e.g., time and one-half for over 8 hours per day or sixth straight day in a week, etc.). Professional (exempt) personnel will be paid straight time for hours worked, given compensatory time off, or some such consideration depending upon local policy, but this also represents cost to the program and must be accounted for.

D.5.4 Field Operations Costs

This is a miscellaneous category that covers costs incurred incidental to field operations and that do not logically fit in any of the foregoing discussions. Included are such items as personnel travel costs and per diem as appropriate, miscellaneous supplies (as opposed to equipment, e.g., ice for samples if required, chemical preservatives, sample containers, gasoline, etc.), performance bonds for site restoration if required, charges for utilities (electricity, telephone lines, etc.), and so on.

TABLE 3-28
ESTIMATED MANPOWER REQUIREMENTS FOR INTENSIVE SURVEYS

Activity	Personnel	Time (man-weeks)	Remarks
Initial planning	Field party chief* and lab personnel	2 MW	Assemble maps and past data
Reconnaissance (if needed)	Field party chief* and biologist	1 MW	Select sampling sites and synoptic biological screening
Mobilize field equipment and crew	Field party chief* technicians and lab crew	1 MW	Get all equipment together and ensure it is in working order
Field sampling	Field party chief* 2 laboratory crew 3 technicians 1 biologist	1 MW 3 MW 4 MW 1 MW	Field sample collection and field lab analyses
Fixed lab analyses chemistry and biology	Chemist Biologist	15 MW 3 MW	Assume 20 samples per day for 15 parameters, chemistry and plankton, and invertebrate identification and enumeration
Data analyses and report preparation	Field party chief* chemist and microbiologist, typist	3 MW	Analyze data, write and type report

* In the case of estuarine or near coastal studies this would be an oceanographer.

Taken individually, these items do not represent major sums of money but, collectively, they form a sum that may not be insignificant for many 208 monitoring programs and, therefore, must be considered in total cost estimation. They are so project and locality specific that no specific guidance can be given for cost estimation. Lacking anything else, add 2 to 5 percent of the total survey cost to cover this category and adjust as appropriate during detailed survey design.

D.5.5 Laboratory Analysis Costs

Use costs for analyses of the selected parameters quoted by the chosen laboratory where possible. Use costs given in the Parameter Handbook for preliminary estimating if local cost data are not available. Add 10 percent to 20 percent to the total for quality control costs.

As an example, Table D-25 contains average analysis costs for the minimum recommended parameter list for characterizing urban runoff. Summing the costs for the individual analyses results in a total estimated analysis cost of $163 per sample. If a sequential discrete sample series of 24 bottles was collected to characterize a storm event, the total lab fee would be $163 x 24 = $3,912. Adding 15 percent for quality control, the final estimated laboratory analysis cost would be approximately $4.5K per storm event. Thus, laboratory analysis costs are one of the major operating costs and may amount to 30 percent to 50 percent of the total cost for this portion of the program budget.

D.5.6 Data Analysis and Reporting

Costs in this category will depend upon the complexity of the survey, the degree of data interpretation required, computer charges for statistical analyses where necessary, and the type of report being generated, e.g., event summary, annual project, etc. Ball park estimates of 20 percent to 30 percent of the estimated professional manpower costs for field work will be adequate in most instances. Use more refined, project specific cost information as it becomes available.

TABLE D-25
AVERAGE ANALYSIS COSTS FOR URBAN RUNOFF PARAMETERS

Parameter	Cost
BOD_5	$ 10
TOD	30
Suspended Solids (NFS)	8
Volatile Suspended Solids	7
Fecal Coliform (MF)	10
Fecal Streptococcus (MF)	10
Nitrate-Nitrite Nitrogen	15
Kjeldahl Nitrogen	15
Total Phosphorous	15
Lead	10
Zinc	10
Copper	10
Chromium	10
pH	3

D.5.7 Example USEPA Costs

Harris and Keffer (16) have provided some information on the costs of a USEPA Surveillance and Analysis Field Investigations Section engaged in effluent monitoring for compliance verification purposes and technical assistance to 208 agencies, e.g., stream monitoring. Major field equipment with approximate initial costs is listed in Table D-26. The Field Investigations Section professional staff includes two sanitary engineers (GS-13 and 11), one chemical engineer (GS-11), and one hydrologist (GS-9). The subprofessional staff consists of four engineering technicians in grades ranging from GS-3 to 6. The regional laboratory, with a staff of eight professional chemists (GS-7 to 13) and three microbiologists (GS-7, 9, and 12), is responsible for operating the mobile laboratories of the section during field surveys.

TABLE D-26
MAJOR FIELD EQUIPMENT AVAILABLE TO USEPA REGION VII SAD FIELD INVESTIGATIONS SECTION

Quantity	Equipment	Approximate Initial Cost
1	Mobile Laboratory	$15,000
1	Mobile Laboratory (on loan)	-
7	GSA Vehicles	-
5	Boats and Motors	5,000
50	Automatic Samplers	28,000
-	Flow-Measuring Devices	6,600
-	Field Analysis Devices	6,100
-	Portable Detector	1,200
1	Metal Detector	300

In areas outside the range in which analytical support can be provided by the regional laboratory, field sampling teams normally operate within a 161-km (100-mile) radius of a mobile laboratory, which is generally set up at a wastewater treatment facility in a community within the area of interest. Because of logistics problems in some of the more sparsely populated areas of the region, it is frequently necessary to work field teams outside of this 161-km (100-mile) radius. Ten to twenty-five percent of the total field activity may be conducted at distances up to 322 km (200 miles) from the laboratory base. Operating at these greater distances reduces capability by an estimated 50 percent and greatly increases the unit cost of sample collection.

Prior to mounting a survey, every effort is made to ascertain and consolidate the various data needs of the Agency and of the State in order to avoid duplication of effort and to minimize the number of laboratory setups. It requires a minimum of 1 week to 10 days to prepare and stock a mobile laboratory; get it on site; have electricity, water, and phone installed; and then torn down and returned to the base station following completion of a survey. If possible, field activities in areas requiring mobile laboratory support are restricted to surveys of 30 days duration or longer.

Under favorable conditions, a mobile laboratory field operation works best with a crew of seven people including: two engineers, two engineering technicians, one chemist, one microbiologist, and one laboratory technician. Working entirely within a 161-km (100-mile) radius of the mobile laboratory, this staff (which is rotated at 2-week intervals) would be able to install samplers and collect approximately 100 samples per week for field and laboratory analyses. Total time and costs for a 30-day field survey are estimated as follows:

Engineers
- 1 man-month office preparation
- 2 man-months field work
- 2 man-months data analyses and report writing

Engineering Technicians
- 2 man-months mobile laboratory and equipment repair and preparation
- 4 man-months field work

Laboratory Personnel
- 6 man-months mobile laboratory work
- 6 man-months regional laboratory analytical work

Clerical
- 2 man-months planning and report preparation

Costs

Salaries	$23,500
Per Diem	7,300
Travel of Personnel	400
Government Bill of Ladings	400
Vehicles	1,000
Miscellaneous Equipment (Ice, batteries, containers, utilities, chemicals, etc.)	1,500
	$34,100

When reviewing the foregoing costs, it should be kept in mind that they do not reflect any burdens (e.g., office space, heating, employee fringe benefits), that equipment costs have increased considerably, and that this team is proficient, well trained, and one of the most efficient in the country.

B.6 Waste Load Allocation Study Procedures

This section contains procedures for conducting a waste load allocation study and some recommendations and guidelines for implementation of the field surveys that will be necessary to carry it out. Most waste load allocation studies will require, as a minimum, one reconnaissance survey and two intensive surveys, one to gather model calibration data and the other to gather verification data. The procedural steps to be followed in conducting a waste load allocation study are outlined in Table B-27.

The first step is to obtain all relevant existing data. This will include all available water quality and flow data for surface water and known sources of wastes. Locations of water use (and a list of legitimate uses) should be determined. Obtain maps and either mark or prepare overlays showing land uses, outfall locations; existing stream gaging and monitoring site locations; stream slopes, cross sections, and flows; locations of rapids, dams, pools, etc.

Analyze the existing data; estimate stream velocities, relative loads from each point source and nonpoint source area, water quality coming into and leaving the planning area, travel times downstream from discharge locations, etc. Use the results to determine first approximations of station locations and parameters to be covered. Plan the reconnaissance survey accordingly. It is recommended that the reconnaissance survey include a toxics scan of all major discharges and others of concern to the 208 agency in order to identify toxic parameters that should be included in the intensive survey.

The next step is the conduct of the reconnaissance survey. The information gathered at this time will form the basis for the intensive survey implementation plan. In conducting the reconnaissance survey, the field survey

TABLE D-27
PROCEDURAL STEPS FOR CONDUCTING A WASTE LOAD ALLOCATION STUDY

(1) Obtain all relevant existing data.

(2) Analyze existing data and perform preliminary calculations.

(3) Based on (1) and (2), plan reconnaissance survey.

(4) Conduct reconnaissance survey.

(5) Analyze results of reconnaissance survey and make preliminary model runs.

(6) Based on (3) and (5), plan calibration survey.

(7) Conduct intensive survey for model calibration.

(8) Reduce data from calibration survey and analyze results.

(9) Fit model using results from (8) and run.

(10) Review results of model runs.

(11) Based on (8) and (10), plan verification survey.

(12) Conduct intensive survey for model verification.

(13) Compare results of verification survey with model predictions.

(14) If results of (13) are favorable, use the model for planning. If not, make adjustments to the model as warranted in view of (13), using the verification data gathered in (12) as additional calibration data. New verification data will now be required, so repeat steps (11) through (13).

manager should be accompanied by persons who supplement his own skills, e.g., if he is a sanitary engineer, he may have with him a biologist and a chemist. The biologist is an especially important member of the reconnaissance team. An experienced aquatic biologist in a very short time can collect and examine bottom organisms that will reveal both the severity of pollution in a general way, and the length of stream affected. His findings can, for example, reveal whether the effects of the wastes have extended farther downstream in the past then they do at the time of the reconnaissance and will have an important influence on the final planning of the study, especially with regard to the number and locations of biological sampling sites.

A quick tour of the area and the streams at readily accessible points may be taken to get the general "lay of the land" and the relationships among water uses, waste sources, and the stream. After this, the individuals of the team may go about their separate duties. The field survey manager needs to cover much of the ground that each of the others does, though in less detail. He must have the entire situation in mind to develop the final study plan, supervise the subsequent field operation, and prepare the report.

The field survey manager should become thoroughly familiar with characteristics of the streams. A trip throughout each reach by boat, if the stream is deep enough, provides the best opportunity for observation. Access to the stream may be limited to bridges and roads that parallel the stream if a boat cannot be used. An overall view of the stream may be obtained from a plane or helicopter, but observation of detail from the height involved is limited. Walking often is difficult because of undergrowth or rough terrain, and can be extremely time consuming unless the stream reach is very short.

Detailed notes of observations should be made promptly; don't depend on memory. Notes should include general impressions of depths, currents, velocities, bends, widths, types of bottom, water uses, waste discharges and mixing of wastes, availability of access, and sensory evidences of pollution, such as excessive plankton or attached growth, floating materials, oil, color, suspended matter, sludge deposits, gas bubbles, and odor. Special attention should be paid to tentative sampling stations selected in the preliminary planning. Accessibility of stations, as well as suitability for sampling, must be considered. Stations should be marked or otherwise identified to ensure sample collection at the proper points. For example, the stream miles may be painted on bridges, with arrows indicating the sampling points.

A dry run of the sampling route or routes should be made and timed. This information will be needed in estimating the final number of sample collectors that will be necessary and the maximum time samples will be held. The routes should be marked on a map, and notes made of any check points that will assist in following the routes. Stream samples for preliminary analysis should be collected at this time to assist in parameter selection for the intensive survey and to familiarize the laboratory personnel with what to anticipate when the study starts, e.g., determination of coliform and BOD will assist in selection of proper dilutions, possible interferences can be identified, etc. Simple field determinations, such as those of temperature, DO, and pH, may be made at the same time.

Potential locations for a mobile laboratory, if one is to be used, should be investigated. Frequently the site is a local water or sewage treatment plant. Accessibility and suitability of an area where the unit may be parked must be considered. Availability of necessary water and electrical connections must be checked. Arrangements for metering water or electricity should be made, if necessary. An area, sewer, or drain to which wastes can be discharged from the laboratory without nuisance is needed. Arrangements for access at any time, day or night, must be made if the area is fenced or otherwise protected. A nearby storage room or space for supplies and materials that are not in immediate use in the laboratory is useful. Convenient telephone service is a must, especially if the laboratory is to serve as headquarters for the field crew.

Facilities may be established in a local laboratory of a water or sewage treatment plant, high school, university, or industrial plant as a substitute for a mobile laboratory. The chemist in the reconnaissance survey crew should review such local facilities to determine their adequacy and what additional equipment and supplies will be needed.

If stormwater runoff is a survey concern, try to include a rainy-day visit as part of the reconnaissance effort. Much valuable information can be obtained, as well as a better appreciation of the conditions the field crew will be working under. For urban areas, sewer maps should be verified as to discharge locations, and the possibility of unrecorded outfalls investigated. Obtain information on traffic density by driving during rush hours and use these travel times for urban field crew logistics planning.

After completion of the reconnaissance survey, analyze the results and make preliminary model runs using the reconnaissance data to get the model segmented properly and to better locate stations. With the results of the reconnaissance survey and model runs as a guide, a workable intensive survey plan may be generated. Start by a careful review of the objectives; can they all be accomplished? Now is the time for any additions or deletions, not halfway through the field activity. Put the detailed plan down in writing and have it reviewed by all involved prior to finalizing. Don't discount helpful comments and suggestions from the field technicians. Include samples of all field data sheets, equipment checklists, etc.

Pay especial attention to all logistics aspects during preparation of the intensive survey plan. For example, if ice is used to cool samples and the survey calls for round-the-clock activity, locate sources where ice can be obtained at odd hours, e.g., automatic machines at service stations, all-night convenience stores, etc., and write them down so all will know. The 25-cent do-it-yourself car wash facilities at some service stations represent sources of high-pressure hot water (and soap, if detergent analyses are not performed) that can be used for cleaning automatic sampling and other field equipment, and their locations should be indicated.

The parameters to be measured must be listed, taking into account the problem assessment of parameters determined from the toxics scan, along with any special handling precautions to be observed, preservatives to be used, sample volumes required, etc. Lists of special supplies and equipment and personnel requirements should be prepared at this time. The funds allocated for the survey and the anticipated cost of the field operations should be reviewed here also.

For around-the-clock survey efforts (with two crews working 12-hour shifts, for example), allow for communication of significant information at shift change by having each shift leader report at least 30 minutes early. If such surveys are for extended periods of time, plan on changing crews every 2 weeks to avoid excessive fatigue. In any event, a system of communication that allows any crew member to be contacted within a reasonable period of time (say 3 hours) is highly recommended. Radios on vehicles are also useful communication aids.

Prepare complete equipment inventories that show locations, status, and maintenance and calibration schedules. Be certain that maintenance responsibilities are clearly defined. In addition to the more obvious equipment, instrumentation, and spares discussed earlier in this Appendix, there are a number of other miscellaneous items that will prove useful in the field, and a few examples will be mentioned. A fairly strong magnet on a line is useful for retrieving metal objects dropped in water. A metal detector is also a handy device at times. A set of basic surveying gear (transit, distance tape or chain, stadia poles, optical rangefinder, etc.) will be useful in some instances. A pick, shovel, ax, and saw will find several applications, such as improving rural stream access for sampling. Some of the basic carpenter's tools on hand will be needed at times. A Danaides (orifice) bucket is useful for estimating moderate pipe discharges into open air. A number of uses will arise for rope, string, wire, and reinforced sticky tape. A walkie-talkie set greatly facilitates communications in the field.

Obviously, not every contingency can be allowed for, and experience in conducting field surveys will facilitate future planning. However, the field survey manager should feel very uncomfortable in reviewing the intensive survey implementation plan if he:

- Does not clearly understand the survey objectives,
- Has strong preconceived notions about the results,
- Has not personally visited each measurement site,
- Has not consulted with laboratory personnel,
- Has not clearly assigned responsibilities,
- Has trusted to luck or favorable opportunities.

Conduct the intensive survey in accordance with the implementation plan insofar as practicable. Be certain that there are compelling reasons for any changes or deviations and document them. The importance of recording all information that might aid in the interpretation and analysis of other data that are being collected has been stressed throughout this Appendix. Even seemingly insignificant bits of information may be very useful in fitting the entire puzzle together. However, if they are not recorded in a clear and intelligible way, they are likely to be lost completely. Never trust to memory.

Field logbooks should be provided to each leader of a survey team and others as appropriate. Standard procedures for field data taking should be observed, e.g., logbooks should be bound with pages numbered serially, entries should be made with ballpoint pen, erasures should never be permitted (use strike-outs), all entries should be signed and dated, etc. Field logbooks should be clearly titled on the cover (to prevent the aquatic biologist from accidentally picking up the equipment crew's log, for example) and should have an assigned location when not in use. The field survey managers should frequently review all field logbooks and initial and date them when this is done.

The field logbooks are the main source of data annotation information. Be sure to record information so that it will be useful to future surveys as well as the present one. For example, entries may range from snake sightings to traffic jams that delayed getting samples to the laboratory. Knowledge of the former can reduce possible future danger to personnel, while information about the latter may suggest the desirability of route alteration. It would be improper to assume the snake would never pose a problem (even if it were killed, others may be around) or that anyone could tell that there had been a delay in getting the samples to the laboratory by comparing the time they were removed from the sampler with the time they were logged in at the laboratory.

The importance of time synchronization of data has been stressed earlier. This is equally important with data annotations. Write down the time of day (use watch time) whenever an entry is made in a field logbook. This will assist in subsequent interpretation. Finally, make full use of field logs and other annotation records in report preparation. The perfect survey has yet to be performed, and mistakes and errors will happen. Sweeping these under the table is much more censorable than admitting that they occurred, especially where a significant impact on data quality or interpretation is likely to result. The worst sin is data fudging (or outright falsification) in an attempt to cover up mistakes. This abhorrent practice should be subject to the most severe reprimand possible. Do not confuse this with data adjustment based on the best available information and professional judgment, e.g., adjustment to a flow record time base to account for a uniformly slow-running clock drive, accounting for a zero offset, etc. Data adjustment is an acceptable practice if it is clearly annotated and explained.

After completing the intensive survey for model calibration, reduce and analyze the data and prepare it for model input. Fit the model using the calibration data and make several runs. After reviewing the results of the calibration survey and the model runs, plan the intensive survey to collect verification data. Unless confidence in the model results is very high, it will be prudent to plan and conduct the verification survey with the same degree of coverage as the calibration survey. Conduct the intensive survey for verification data following the above guidance for the calibration survey and taking advantage of lessons learned from it.

Finally, compare the results of model runs with the data gathered during the verification survey. If the comparison is favorable, the model may be considered verified and can be used for waste load allocation planning. If differences are significant, make adjustments to the model as warranted from a review of the discrepancies between the model predictions and the results of the verification survey, using the verification data now as additional calibration data. Once this latter step is done, there is no longer any information about the verification of the model. The importance of this point must not be overlooked. To verify the model it will be necessary to plan and conduct another intensive survey solely for this purpose. In many instances, however, it will not need to be as extensive as the earlier intensive surveys, since the level of confidence in model results should be considerably higher than before.

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APPENDIX E

DOCUMENTATION FOR SYNOPTIC RAINFALL DATA ANALYSIS PROGRAM - SYNOP

E.1 Introduction

An integral part of the assessment of storm loads on water quality, is the statiscical evaluation of rainfall records. Hourly rainfall records of many years duration are cumbersome and difficult to analyze. Tools to summarize the variables of interest (volume, duration, intensity, and time between storms) are needed to determine seasonal trends which are of importance in assessing impacts and selecting control alternatives for storm related loads. The purpose of the SYNOP rainfall data analysis program is to provide the user with a tool for summarizing and statistically characterizing a rainfall record of interest. Copies of the Synoptic Rainfall Data Analysis Program (SYNOP) with sample rainfall tapes and documentation can be obtained at a modest cost from:

National Technical Information Service
Office of Computer Products
5285 Port Royal Road
Springfield, Virginia 22161

E.2 Description

Hourly rainfall data is obtained for a minimum of five years of record to provide sufficient confidence in the rainfall characterization. Longer term records covering many years are preferable and are usually available from U.S. Weather Bureau Stations.

The hourly data are then summarized by storm events, each with an associated unit volume (V, inches), duration (D, hours), average intensity (I = V/D, inches/hour), and time since the previous storm (Δ, hours) measured from the midpoint of the successive storms. A storm definition must be established to determine when, in the hourly record, a storm begins and ends. Program SYNOP delineates storm events as rainfall periods separated by a minimum number of consecutive hours without rainfall. The recommended number of hours without rainfall is 3 hours.

The statistics of relevant storm parameters are then computed. The mean and the coefficient of variation of each parameter are determined: the mean is the arithmetic average; the coefficient of variation is defined as the standard deviation divided by the mean. The parameters of interest are storm intensity, duration, unit volume and time between storms. At the end of each year, a histogram is produced showing the amount of rainfall for each hour of the year.

After the complete period of record has been read, the following operations are performed on duration, D, intensity, I, volume, V, and delta, Δ:

1. Statistics by month
2. Plot of average and standard deviation by month
3. Statistics by year
4. Plot of averrge and standard deviation by year
5. Percent of occurrences less than or equal to the given value (and associated plot)
6. Return period in years and associated plot.

E.3 Input Structure

The usual method for transmitting rainfall data is via magnetic tape. SYNOP has been written assuming that the data is aligned on a U.S. Weather Bureau tape in chronological order within each station. There is no logical separation between stations and a tape marker appears at the end of a file. Sometimes, depending on the retrieval system used to generate the tapes, stations are divided by time periods among several tape files. The various possibilities have been accounted for by the several fields that appear on the control card. For each station, at least one control card is needed for each tape file. The user concludes his input deck with a card containing a /* in columns 1 and 2.

E.3.1 Control Card Description

6	8	10	15	20	25	30	35	41	(Ending Col. Nos.)
ISTA	IRQYR	IRWD	STMDF	ISKIP	IPAUS	IDISM	ICNST	TAPEN	

FORMAT (A6, A2, I2, 5I5, 3A2)

ISTA = desired station number (station number is defined by the U.S. Weather Bureau)

IRQYR = last 2 digits of year number where execution is to begin. If left blank, then the execution will begin at the first hourly rainfall record.

IRWD = 0, begin search immediately (used for initial search)
1, rewind tape before beginning search (used as required in subsequent searches)

STMDF = storm definition, number of consecutive hours without rainfall which indicates the end of a storm (3 hours is recommended)

ISKIP = 0, print hourly rainfall data
1, skip printing hourly rainfall data

IPAUS = 0, indicates that data for the requested station will end after the present tape file has been read.
1, indicates that more data for the requested station is expected after the present tape file has been read. The program will pause to allow the operator to change tapes if necessary.

IDISM = 0, no rewind after the present tape file has been read.
1, rewind and dismount tape after file has been read.
IDISM = 1 for last analysis on a tape.

ICNST = 0, data for the requested station begins with the current tape.
1, data for the requested station is being continued from a previous tape file.

TAPEN = next tape number to be mounted (is printed on the console typewriter as an operator instruction).

In the example shown in Table E-1, 2 stations are requested. Station 410016 appears on 4 tape files (thus requiring 4 control cards) and Station 052220 appears on only one tape file. A brief explanation of this data input follows.

Card Number	Explanation
1	Station 410016; rewind tape before beginning search; 3 consecutive dry hours define end of storm; print hourly data; pause after reading tape file because more data is expected; rewind after tape file has been read; data for 410016 begins with this tape file; next tape is W1036.
2	Station 410016; starting in 1962; rewind tape before search begins; 3 consecutive dry hours end storm; print hourly data; pause after reading tape file because more data is expected; rewind after tape file has been read; this is a continuation of Station 410016; next tape is W3375.
3	Same as 2, but do not rewind after station has been read and start at first hourly rainfall record. Note that the next tape to be mounted is W3375 (the same as the present tape). No rewinding is done since the next set of data is on the next file on the same tape.
4	Begin in 1974; do not rewind tape before search begins; 3 consecutive dry hours end each storm; print hourly data; end of station will be recognized after this tape file has been read; rewind tape after tape file has been read; this is a continuation of Station 410016.
5	Station 052220; rewind tape before beginning search; 3 consecutive dry hours define the end of storm; print hourly data; end of station after this tape file has been read.
6	End of input data deck.

TABLE E-1

INPUT STRUCTURE FOR PROGRAM STRIP

Card No.	ISTA	IRQYR	IRND	STMDF	ISKIP	IPAUS	IDISM	ICNST	TAPEN
1	410016		1	3	0	1	1	0	.1336
2	410016	62	1	3	0	1	1	1	.5375
3	410016		1	3	0	1	0	1	.5375
4	410016	74	0	3	0	0	1		
5	052220		1	3	0	0	0		
6	/*								

E.4 Source Listing of Program SYNOP

Program SYNOP is written in FORTRAN IV, Level G for IBM 1130 compatible computer systems. Minor changes in the coding of input-output functions will facilitate its use on other computer systems. The program nominally uses a high speed printer, a disk drive, a magnetic tape drive, and a card reader.

This section presents a flow chart of the SYNOP program and a complete listing of the FORTRAN source code. Section E.5 presents an example execution of program SYNOP.

E.4.1 Flow Chart For Program SYNOP

A flow chart for program SYNOP is presented on the following two pages.

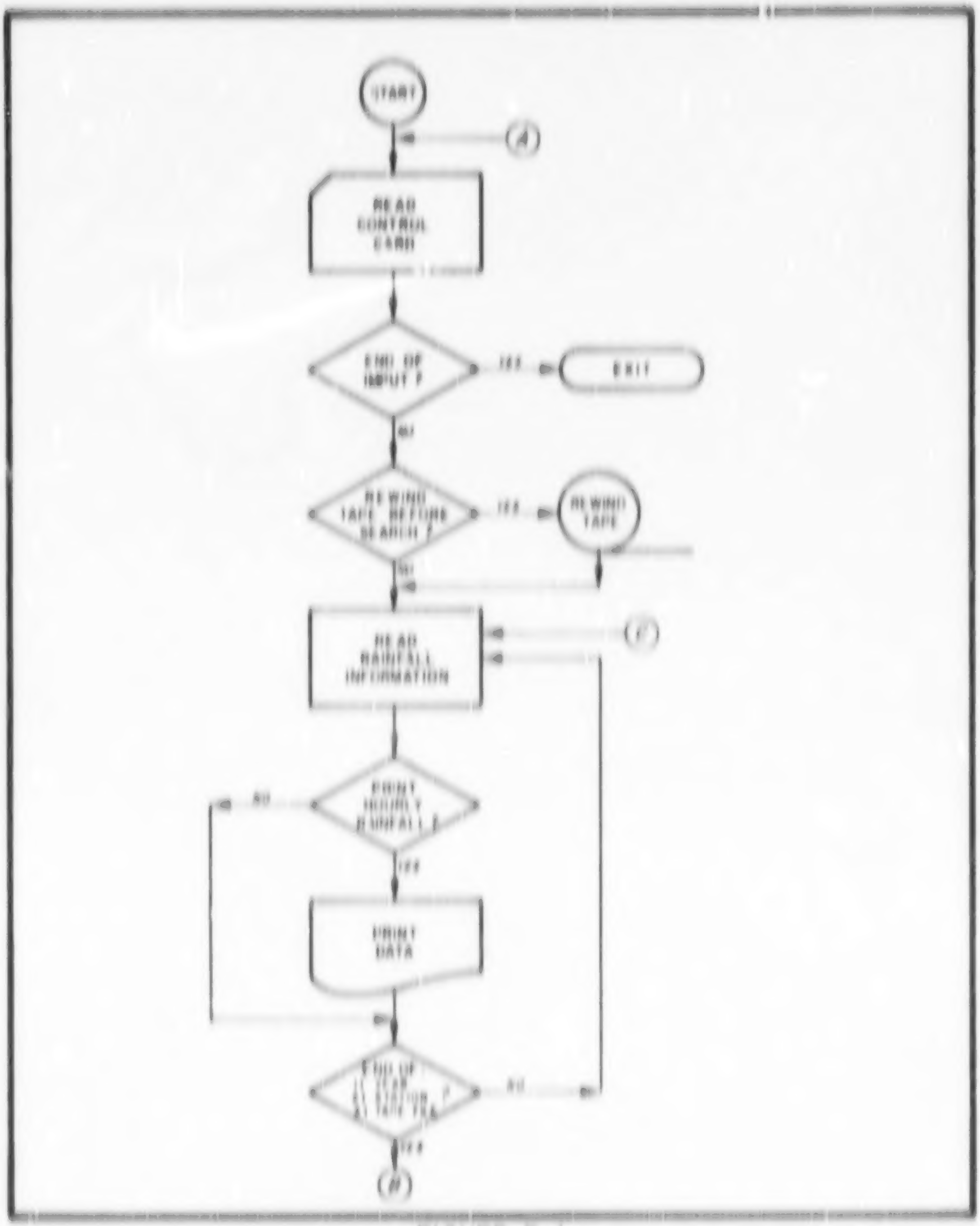

FIGURE E-1

FLOW CHART FOR PROGRAM 'SYNOP'

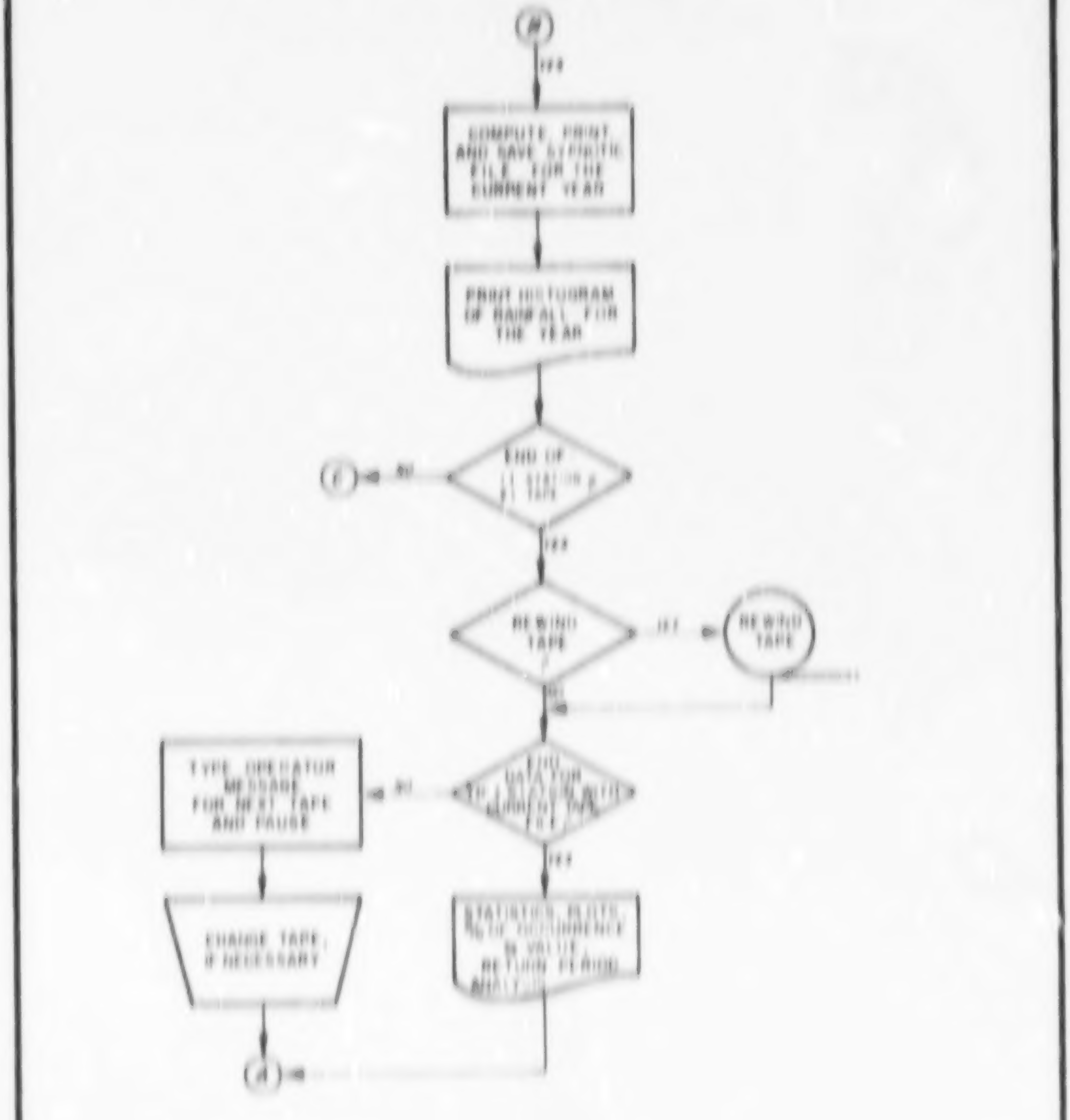
H
YES
COMPUTE, PRINT AND SAVE SYNOPTIC FILE FOR THE CURRENT YEAR
PRINT HISTOGRAM OF RAINFALL FOR THE YEAR
END OF STATION ON TAPE
NO
C
YES
REWIND TAPE ?
YES
REWIND TAPE
NO
END DATA FOR STATION WITH CURRENT TAPE ?
NO
TYPE OPERATOR MESSAGE FOR NEXT TAPE AND PAUSE
CHANGE TAPE, IF NECESSARY
YES
STATISTICS, PLOTS, % OF OCCURRENCE & VALUE, RETURN PERIOD ANALYSIS
A

FIGURE E-1(CONT'D)

FLOW CHART FOR PROGRAM 'SYNOP'

E.1.2 Source Listing for Program SYNOP

```
C          ***** SUBROUTINE [illegible] *****
C
      SUBROUTINE [illegible] (X,Y,XMAX,XMIN,YMAX,YMIN,NTOT,NPLT,NLINE,NSPA,
     1ICODE,INPG,ISIDE,ISYM)
C
C     THIS SUBROUTINE WILL PLOT UP TO 10 SIMULTANEOUS PLOTS IN THE SAME
C     GRAPH
C     IT WILL ALSO PLOT 2 GRAPHS SIDE BY SIDE IF ISIDE IS SET EQUAL TO 1
C
C     X=ARRAY OF X'S (1-DIMENSIONAL ARRAY, FIRST NTOT REPRESENT X1, SECOND
C     NTOT REPRESENT X2, ETC.)
C     Y=ARRAY OF Y'S (1-DIMENSIONAL ARRAY, FIRST NTOT REPRESENT Y1, SECOND
C     NTOT REPRESENT Y2, ETC.)
C     WHEN USING THE OPTION TO PLOT 2 GRAPHS SIDE BY SIDE, THEN INPUT
C     THE X'S AND Y'S AS FOLLOWS:(1)
C     THE FIRST [illegible] ARE FOR THE LEFT GRAPH AND THE NEXT NTOT(2)
C     *NPLT(2) ARE FOR THE RIGHT GRAPH
C     XMAX=MAXIMUM VALUE IN X-DIRECTION
C     XMIN=MINIMUM VALUE IN X-DIRECTION
C     YMAX=MAXIMUM VALUE IN Y-DIRECTION
C     YMIN=MINIMUM VALUE IN Y-DIRECTION
C     NTOT=NUMBER OF POINTS PER PLOT
C     NPLT=NUMBER OF PLOTS
C     THERE IS A XMAX, XMIN, YMAX, YMIN, NTOT, NPLT FOR EACH GRAPH IF 2 ARE
C     BEING USED
C     NLINE=NUMBER OF LINES IN Y-DIRECTION
C     NSPA=NUMBER OF SPACES IN THE X-DIRECTION FOR EACH GRAPH
C     ICODE=0 IF ONLY ONE SET OF X'S ARE TO BE PLOTTED
C     ICODE=1 IF MORE THAN ONE SET OF X'S ARE TO PLOTTED
C     NOTE:=EXCEPT WHEN ICODE IS 0, DIMENSION X AND Y BY NTOT*NPLT IN THE
C     MAINLINE;
C     WHEN ICODE=0, DIMENSION Y BY NTOT*NPLT, AND X BY NTOT IN THE MAINLINE;
C     INPG=OPTION NOT TO SKIP TO A NEW PAGE EACH TIME [illegible] IS CALLED;
C                INPG=0:SKIP TO A NEW PAGE
C                INPG=1:DO NOT SKIP TO A NEW PAGE
C     ISIDE DETERMINES WHETHER 1 OR 2 GRAPHS WILL BE PLACED SIDE BY SIDE
C         ISIDE=0:1 PLOT ON PAGE
C         ISIDE=1:2 ADJACENT GRAPHS WILL BE PLOTTED
C
C     ISYM=VECTOR OF SUBSCRIPTS CORRESPONDING TO SYMBOLS TO BE PLOTTED
C     FOR EACH OBSERVATION
C     TABLE OF CORRESPONDING SYMBOLS::
C
C     NUM SYMB      NUM SYMB      NUM SYMB      NUM SYMB      NUM SYMB      NUM SYMB
C       1   1         9   9        17   G        25   O        33   W        41   [illegible]
C       2   2        10   0        18   H        26   P        34   X        42   (
C       3   3        11   A        19   I        27   Q        35   Y        43   )
C       4   4        12   B        20   J        28   R        36   Z        44
C       5   5        13   C        21   K        29   S        37   +        45   .
C       6   6        14   D        22   L        30   T        38   -        46   ,
C       7   7        15   E        23   M        31   U        39   *        47   [illegible]
C       8   8        16   F        24   N        32   V        40   /
      DIMENSION X(1),Y(1),IY(101)
      DIMENSION XMAX(2),XMIN(2),YMAX(2),YMIN(2),XSCAL(2),YSCAL(2),L(2)
      DIMENSION YVAL(2),IC(10,2),NTOT(2),NPLT(2),ICODE(2)
      DIMENSION [illegible]          [illegible]
      DATA [illegible]
      DATA (A/'1','2','3','4','5','6','7','8','9','0','A','B','C','D','E
     &','F','G','H','I','J','K','L','M','N','O','P','Q','R','S','T','U',
     &'V','W','X','Y','Z','+','-','*','/','(',')',[illegible]
     &'.',' '/
      [illegible]
C           SET ARRAY  IC  DIMENSIONED 10 X 2 EQUAL TO 1
      CALL SETIA(IC,10,2,1)
      DO 16 I=1,2
C           CALCULATE INTERVAL BETWEEN PRINT POSITIONS ON X-AXIS AND
C           BETWEEN LINES ON Y-AXIS
      XSCAL(I)=(XMAX(I)-XMIN(I))/FLOAT(NXSPA)
      YSCAL(I)=(YMAX(I)-YMIN(I))/FLOAT(NLINE)
C           E=HALF THE INTERVAL IN THE Y-DIRECTION (EPSILON)
   16 E(I)=YSCAL(I)/2.
C           NGRTO=NUMBER OF POINTS X NUMBER OF PLOTS,  GRAND TOTAL
C           OF THE NUMBER OF POINTS ON THE LEFT SIDE GRAPH,
      NGRTO=NTOT(1)*NPLT(1)
C           CHECK IF NEW PAGE IS DESIRED
      IF (INPAG .NE. 1) WRITE (IO,202)
  202 FORMAT (1H1)
C           LXSPA=NUMBER OF X-SPACES ON X-AXIS
    1 LXSPA=NXSPA/5
C           PRINT OUT TOP BORDER
      WRITE(IO,203) (ABC(1),(BX(1),I=1,LXSPA)
  203 FORMAT (1X,'(1',20(A4,A1))
C           CHECK IF TWO GRAPHS SIDE BY SIDE ARE DESIRED
      IF (ISIDE-1) 85,15,85
C           IF THEY ARE, PRINT TOP BORDER FOR RIGHT GRAPH,
   15 WRITE(IO,205)(ABC(1),(BX(1),I=1,LXSPA)
  205 FORMAT (1H+,67X,'I',20(A4,A1))
   85 IXSPA=NXSPA+1
      KXSPA=NXSPA+2
      NLIN=NLINE+1
C           NS=NUMBER OF SIDE BY SIDE GRAPHS
      NS=1+ISIDE
      DO 18 K=1,NLIN
C           SET OUTPUT LINE TO BLANKS
      CALL SETIA(IY,102,1,IBL)
C           SET RIGHT SIDE OF LINE TO BLANKS
      CALL SETIA(IYY,51,1,IBL)
C           SET LAST ELEMENT OF LINE TO AN 'I'
      IY(KXSPA)=IVBIN
      IF (ISIDE-1) 88,87,88
C           IF SIDE BY SIDE IS CHOSEN, SET LAST ELEMENT OF RIGHT SIDE
C           TO AN 'I'
   87 IYY(IXSPA)=IVBIN
   88 DO 18 N=1,NS
C           YVAL=VALUE OF CURRENT POSITION ALONG Y-AXIS,  BEGINNING
C           AT TOP OF THE GRAPH WITH A VALUE OF  YMAX  AND DECREASING
C           BY A VALUE OF  YSCAL  FOR EACH LINE)
      YVAL(N)=YMAX(N)-(K-1)*YSCAL(N)
C           NP=NUMBER OF PLOTS ON THIS SIDE
      NP=NPLT(N)
C           NT=NUMBER OF POINTS ON THIS SIDE
      NT=NTOT(N)
C           I LOOP IS FOR EACH PLOT
      DO 9 I=1,NP
```

```
C          11 LOOP IS FOR EACH POINT
      DO 11 K=1,NT
C          CHECK IF COUNTER FOR THIS PLOT EXCEEDS NUMBER OF POINTS
C          FOR THIS PLOT
      IF(IC(I,M)-NT)  20,20,9
C          IF NOT, SET J EQUAL TO CURRENT COUNTER VALUE
   20 J=IC(I,M)
C          I1=SUBSCRIPT OF CURRENT POINT
      I1=[illegible]
C          TEST=DIFFERENCE BETWEEN Y VALUE OF CURRENT POINT AND CUR-
C          RENT Y POSITION
      TEST   =ABS(Y(I1)-YVAL(Y))
C          IF TEST IS LESS THAN OR EQUAL TO EPSILON, THIS POINT IS TO
C          BE PLOTTED ON CURRENT LINE
      IF(TEST-[illegible]) 12,12,5
C          IF TEST IS GREATER THAN EPSILON, SEE IF Y-VALUE OF CURRENT
C          POINT IS GREATER THAN CURRENT Y POSITION
    5 IF( Y(I1)-YVAL(M))  9,9,6
C          IF IS GREATER, THEREFORE INCREASE COUNTER AND GO TO NEXT
C          POINT
    6 IC(I,M) = IC(I,M)+1
      GO TO 11
C          TEST INDICATES THE POINT IS TO BE PLOTTED ON THIS LINE
C          I2=CORRESPONDING SUBSCRIPT IN X-DIRECTION
   12 I2=[illegible]
C          UPDATE COUNTER
      IC(I,M) = IC(I,M)+1
C          IPOS=POSITION ALONG X-AXIS
      IPOS=(X(I2)-XMIN(M))/XSCAL(M)+1.5
C          IF  IPOS  IS LESS THAN 1 OR GREATER THAN THE NUMBER OF
C          POSITIONS IN THE X-DIRECTION, THEN DON'T PLOT IT
      IF( IPOS.GT.IXSPA.OR.IPOS.LT.0 )   GO TO 11
      IF (K-1) 55,55,52
   55 IF (NSYM .NE. 0) IA=ISYM(I)
      IF (NSYM .EQ. 0) IA=NN
      LN(IPOS)=[illegible]
      GO TO 11
   52 IA=ISYM(I)
      [illegible]
   11 CONTINUE
    9 CONTINUE
   10 CONTINUE
      IF (ISTYP-1) 54,55,59
   54 WRITE([illegible])
  200 FORMAT ([illegible])
      GO TO 13
   56 WRITE([illegible])
  206 FORMAT ([illegible])
      WRITE([illegible])
  207 FORMAT ([illegible])
   13 CONTINUE
      DO 18 I=1,20
   18 [illegible]
      WRITE([illegible])
      IF ([illegible]) 58,59,58
   58 WRITE([illegible])
   59 [illegible]
```

```
      DO 17 M=1,NP
      I0=M*5-4
      I1=I0+NSPA+1
      DO 17 I=I1,I2
   17 FSCAL(I)=[illegible]
      WRITE(6,205) (FSCAL(J),J=I1,NSPA)
  205 FORMAT (A5,11F10.2)
      IF (ISIDE-1) 60,55,60
   55 WRITE(6,210)(FSCAL(J),J=1,10)
  210 FORMAT (1H ,A10,5F10.2)
   60 RETURN
      END
C
C
C           ***** SUBROUTINE DATCA *****
C
      SUBROUTINE DATCA(IDATN,MONTH,DAY,YEAR)
      INTEGER MOS(12),MONTH,DAY,YEAR
      DATA MOS/31,0,31,30,31,30,31,31,30,31,30,31/
      IDATE=0
      DO 10 YEAR=1,99
      NDAYY=365
      IF (YEAR/4*4 .EQ. YEAR) NDAYY=366
      IDATE=IDATE+NDAYY
      IF (IDATE .GE. IDATN) GO TO 20
   10 CONTINUE
   20 IDATE=IDATE-NDAYY
      MOS(2)=28
      IF (YEAR/4*4 .EQ. YEAR) MOS(2)=29
      DO 30 MONTH=1,12
      IDATE=IDATE+MOS(MONTH)
      IF (IDATE .GE. IDATN) GO TO 40
   30 CONTINUE
   40 NDAYM=MOS(MONTH)
      IDATE=IDATE-NDAYM
      DO 50 DAY=1,NDAYM
      IDATE=IDATE+1
      IF (IDATE .GE. IDATN) RETURN
   50 CONTINUE
      RETURN
      END
C
C
C           ***** SUBROUTINE SHELL *****
C
C     SHELL SORT
C     REFERENCES..
C         D.L.SHELL, CACM, VOL 2 (1959), PP 30,32
C         T.N. HIBBARD, SDC REPORT SP-982
C         J.BOOTHROYD, CACM, ALGORITHM 201
C     THIS IS A FORTRAN VERSION OF ALGORITHM 201.
C     SUBROUTINE SHELL (IA,N,NROW,NCOL,JR,ID)
C     IA=INPUT ARRAY TO BE ARRANGED
C     N=NUMBER OF ELEMENTS (FILLED ROWS) IN IA
C     NROW=NUMBER OF ROWS IN IA
C     NCOL=NUMBER OF COLUMNS IN IA
C     JR=ARRAY CONTAINING HIERARCHY OF COLUMNS TO DETERMINE
```

```
C             FINAL ARRANGEMENT OF IA (JA(LAST)=1=0)
C      ID=ARRAY IN 1 TO 1 CORRESPONDANCE WITH JA TO DETERMINE DIRECTION OF
C              SORT:  ID=1...ASCENDING
C                     ID=2...DESCENDING
      DIMENSION IA(1),ID(1),JA(1)
      INTEGER ITEST1,ITEST2
C     FIND M=ONE LESS THAN LEAST POWER OF 2.GT.N
      M=0
   10 M=M+M+1
      IF (N-M) 10,20,70
C  20 OUTER LOOP, ,HALVE M,
   20 M=M/2
C     TEST FOR END OF OUTER LOOP,
      IF (M) 70,70,30
C  30 FIND LIMIT FOR MIDDLE LOOP
   30 K=N-M
C     BEGIN MIDDLE LOOP
      DO 60 J=1,K
C     SETUP FOR INNER LOOP
      I=J
C  40 MIDDLE AND INNER LOOP , , COMPARE,
   40 L=I+M
      LJ=1
   25 IAD=NROW*(JA(LJ)-1)
      L1=L+IAD
      I1=I+IAD
      IDEC=ID(LJ)
      ITEST2=IA(L1)
      ITEST1=IA(I1)
      GO TO (21,22),IDEC
   21 IF (ITEST1-ITEST2) 60,61,50
   22 IF (ITEST1-ITEST2) 50,61,60
   61 LJ=LJ+1
      IF (JA(LJ)) 60,60,25
C  50 NOT IN SEQUENCE, SO SWAP
   50 DO 80 IP=1,NCOL
      NROCD=NROW*(IP-1)
      NI=NROCD+I
      NL=NROCD+L
      ITEMP=IA(NI)
      IA(NI)=IA(NL)
   80 IA(NL)=ITEMP
C     GO DOWN INNER LOOP , , ONLY IF SWAP
      I=I-M
C     TEST FOR END OF INNER LOOP
      IF (I) 60,60,40
C  60 END OF INNER AND MIDDLE LOOP,
   60 CONTINUE
      GO TO 20
C  70 SORT COMPLETE
   70 RETURN
      END
C
C
C             ***** SUBROUTINE SHELM *****
C
C     SHELL SORT
```

```
C     REFERENCES..
C        D.A.SHELL, CACM, VOL 2 (1959), PP 30..32
C        T.N. HIBBARD, SDC REPORT SP-982
C        J.BOOTHROYD, CACM, ALGORITHM 201
C     THIS IS A FORTRAN VERSION OF ALGORITHM 201.
      SUBROUTINE SHELL ( A,N,NROW,NCOL,JR,ID)
C      A=INPUT ARRAY TO BE ARRANGED
C     N=NUMBER OF ELEMENTS (FILLED ROWS) IN  A
C     NROW=NUMBER OF ROWS IN  A
C     NCOL=NUMBER OF COLUMNS IN  A
C     JR=ARRAY CONTAINING HIERARCHY OF COLUMNS TO DETERMINE
C              FINAL ARRANGEMENT OF  A (JR(LAST+1)=0)
C     ID=ARRAY IN 1 TO 1 CORRESPONDANCE WITH JR TO DETERMINE DIRECTION OF
C           SORT,  ID=1..ASCENDING
C                  ID=2..DESCENDING
      DIMENSION  A(1),ID(1),JR(1)
C     FIND M=ONE LESS THAN LEAST POWER OF 2.GT.N
      M=0
   10 M=M+M+1
      IF (M-N) 10,20,20
C  20 OUTER LOOP, HALVE M.
   20 M=M/2
C     TEST FOR END OF OUTER LOOP.
      IF (M) 70,70,30
C  30 FIND LIMIT FOR MIDDLE LOOP
   30 K=N-M
C     BEGIN MIDDLE LOOP
      DO 60 J=1,K
C     SETUP FOR INNER LOOP
      I=J
C  40 MIDDLE AND INNER LOOP . . COMPARE.
   40 L=I+M
      LJ=1
   25 IAD=NROW*(JR(LJ)-1)
      LL=L+IAD
      II=I+IAD
      IDEC=ID(LJ)
      GO TO (21,22),IDEC
   21 IF ( A(II)- A(LL)) 60,61,50
   22 IF ( A(II)- A(LL)) 50,61,60
   61 LJ=LJ+1
      IF (JR(LJ)) 60,60,25
C  50 NOT IN SEQUENCE, SO SWAP
   50 DO 80 IP=1,NCOL
      NROWIP=NROW*(IP-1)
      NI=NROWIP+I
      NL=NROWIP+L
       TEMP= A(NI)
       A(NI)= A(NL)
   80  A(NL)= TEMP
C     GO DOWN INNER LOOP . . ONLY IF SWAP
      I=I-M
C     TEST FOR END OF INNER LOOP
      IF (I) 60,60,40
C  60 END OF INNER AND MIDDLE LOOP.
   60 CONTINUE
      GO TO 20
```

```
C   70 SORT COMPLETE
    70 RETURN
       END
C
C
C             ***** FUNCTION IDATE *****
C
       FUNCTION IDATE(IDAY,MONTH,IYEAR)
       IDATE=IDAY
       JYEAR=IYEAR-1
       DO 300 I=1900,JYEAR
       IF((I/4)*4-I)200,200,100
  100  IDATE=IDATE+365
       GO TO 300
  200  IDATE=IDATE+366
  300  CONTINUE
       IF((IYEAR/4)*4-IYEAR)400,500,400
  400  IFEB=28
       GO TO 600
  500  IFEB=29
  600  GO TO (1,2,3,4,5,6,7,8,9,10,11,12),MONTH
  12   IDATE=IDATE+30
  11   IDATE=IDATE+31
  10   IDATE=IDATE+30
   9   IDATE=IDATE+31
   8   IDATE=IDATE+31
   7   IDATE=IDATE+30
   6   IDATE=IDATE+31
   5   IDATE=IDATE+30
   4   IDATE=IDATE+31
   3   IDATE=IDATE+IFEB
   2   IDATE=IDATE+31
   1   RETURN
       END
C
C
C             ***** SUBROUTINE SETIA *****
C
       SUBROUTINE SETIA (IARAY,NROW,NCOL,IVALU)
C             SET INTEGER ARRAY DIMENSIONED  NROW X NCOL  TO  IVALU
       INTEGER IARAY(1)
       NELEM=NROW*NCOL
       DO 10 I=1,NELEM
       IARAY(I)=IVALU
    10 CONTINUE
       RETURN
       END
C
C
C
C             ***** PROGRAM SYSOP *****
C
C
C
C
C             NOTE THAT ALL SOURCE CARDS DENOTED BY A 'S' IN COLUMN 73
C                 ARE NEEDED TO ACCESS THE OSU/NCTA'S TAPE DRIVE AND
C                    SHOULD EITHER BE REPLACED OR ELIMINATED.  SUGGESTED
C                    REPLACEMENT STATEMENTS ASSUME THAT  99  IS SPECIFIED
```

```
C            AS THE TAPE DEVICE CODE.
C
C
C
C
      INTEGER JH1(2)
      INTEGER JH3(2)
      INTEGER YSPAC(2),BLANK
      INTEGER ISTA(5),KEY(3800,3),JPL(7),JHP(5)
      INTEGER TITLE(5,4),DASH(15,2)
      INTEGER ICOUNT(5,20)
      INTEGER ICARD(9)
      INTEGER YEAR,MONTH,DAY,CARD,RAIN(12),STA(6),PREST(6)
      INTEGER IHOUR(366,27),DRY,IWET,PRECIP,STORM,NSTRM,JSTRM,FSTRM,HSTRM
      INTEGER DURAT,STOP,DURLS,COUN
      INTEGER IBUF(400)
      INTEGER ISAVE(3)
      INTEGER IS,N(100),TAPE(3)
      INTEGER AUSST
      REAL PLOT(60,5)
      REAL XVALU(3800,2)
      REAL ZPAR(3)
      REAL X(30),Y(30,8),XMAX(2),XMIN(2),YMAX(9)
      REAL ITEM
      REAL RESV(9),STAT(9,8)
      EQUIVALENCE (KEY(1,1),IHOUR(1,1))
      EQUIVALENCE (XVALU(1,1),KEY(1,1))
      DATA JPL/1,3,8/,JHP/1,1,8/
      DATA JH3/2,8/
      DATA JH1/1,8/
      DATA DASH/2/,WET/6/
      DATA IAST/1H*/
      DATA XMIN/0.,0./,XMAX/12.,90./,YSPAC/60.,80/,BLANK/  /
      DATA MARK/' MONTH  YEAR'/
      DATA TITLE/'DURATION  INTENSITY VOLUME    DELTA     '/
      DATA AUSST/[illegible]/
      DEFINE FILE 98(10,90,U,LOC98)
      DEFINE FILE 96(1200,80,U,LOC96)
      DEFINE FILE 99(10,80,U,LOC99)
      IN=8
      IO=5
      ITIP=1
C
C            START TAPE AT SPECIFIED STATION
C
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
      LOC99=11                                                          *
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
C
C            READ CONTROL CARD
C     ISTA=STATION NUMBER
C     IBYR=LAST 2 DIGITS OF YEAR TO BEGIN ANALYSIS; IF OMITTED, THEY
C          BEGIN AT FIRST HOURLY RAINFALL ON UNIT
C     IRWD=1 TO REWIND TAPE BEFORE SEARCH...;0=DON'T REWIND; 1=REWIND
C     NINC=NUMBER OF CONSECUTIVE DRY HOURS THAT DEFINE THE END OF THE
C          STORM
C     ISKIP=1 TO SKIP PRINTING OF HOURLY RAINFALL DATA; 0=PRINT.
```

```
C          1=OUTPUT PRINT
C     IPAUS=CODE TO PAUSE AFTER THIS STATION ON TAPE HAS BEEN READ,
C          0=END OF STATIONS AFTER THIS READ OF TAPE, 1=PAUSE-CONTINUE
C          STATION ON NEXT FILE OR NEXT TAPE.
C     IDISM=CODE TO REWIND (DISMOUNT) TAPE AFTER STATION ON TAPE HAS
C          BEEN READ,  0=DO NOT REWIND, 1=REWIND
C     ICNST=CODE THAT INDICATES THAT STATION IS BEING CONTINUED FROM A
C          PREVIOUS TAPE OR FILE,  0=NEW STATION-START HERE, 1=CONTINUE
C     TAPEN=NUMBER OF NEXT TAPE TO BE MOUNTED.
    1 READ (15,1020,END=999)ISTA,IYRYR,IRWD,STNOF,ISKIP,IPAUS,IDISM,
     1                    ICNST,TAPEN
C
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
      CALL E9999                                                        *
      GO TO 1
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
C
C              CHECK FOR REWINDING TAPE
C
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
 9998 IF (IRWD .EQ. 1) CALL MASTAT(8,0)                                 *
      IRECD=1                                                           *
      IF (IRWD .EQ. 1 .OR. IRECD .GT. 10) GO TO 2                       *
      READ (99'1) IBUF                                                  *
      IRECD=LRECD                                                       *
      GO TO 510                                                         *
C             READ A BLOCK OF TAPE                                      *
    2 CALL MAGTA (8,0,500,IBUF(21))                                     *
C             CONVERT TO IBM 1130                                       *
      CALL EBCLM (500,IBUF)                                             *
  510 DO 9 I=IRECD,10                                                   *
      ISUB=(I-1)                                                        *
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
C             REPLACE BY
C     IF (IRWD .EQ. 1) REWIND 99
C   2 READ (99,1030,END=11) (IBUF(J),J=1,19)
C1030 FORMAT (9A2)
C     K=0
C
      CALL DATSW(10,ISWD)
      IF (ISWD .EQ. 1) GO TO 910
C             CHECK FIRST 6 CHARACTERS OF EACH RECORD FOR DESIRED
C             STATION
         DO 8 J=1,3
         K=K+1
         IF(IBUF(K+ISUB) .NE. ISTA(J)) GO TO 9
    8    CONTINUE
C             IF REQUESTED YEAR EXISTS, CHECK THAT IT MATCHES
      IF (IRGYR .NE. BLANK .AND. IRGYR .NE. IBUF(K+1)) GO TO 9
C             DESIRED STATION FOUND
C
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
      WRITE (99'1) IBUF                                                 *
      CALL DUMP                                                         *
      LRECD=I                                                           *
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
C             REPLACE BY
```

```
C     BACKSPACE 99
C
      GO TO 5
    4 CONTINUE
      IRECD=1
      GO TO 7
    5 CONTINUE
C
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
C                SET UP FOR END-OF-TAPE MARKER                              *
      CALL EVOSD                                                            *
      GO TO 900                                                             *
 9999 CONTINUE                                                              *
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
C
C                RESET INITIAL CONDITIONS FOR NEW STATION
      IF (ICVRT .EQ. 1) GO TO 8
      LOC99=1
      DURLT=0
      COND=DRY
      NDRY=0
      NORUN=0
      VOLUM=0
      DURAT=0
      STORM=0
      NOYRS=0
    8 CONTINUE
      ILSTC=0
C                READ STATION NUMBER AND YEAR FROM NEXT RECORD
C
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
      READ (99'LOC99,1000) STA,NEWYR                                        *
      LOC99=LOC99+1                                                         *
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
C                REPLACE BY
C     READ(99,1000,END=9999)STA,NEWYR
C     BACKSPACE 99
C
      NEWYR=NEWYR+1900
      DO 6 I=1,6
      PRESI(I)=STA(I)
    6 CONTINUE
C                CLEAR THIS YEAR'S MATRIX
    7 CONTINUE
      CALL SETIA(IHOUR,366,24,0)
C                COMPUTE STARTING DAY NUMBER FOR THIS YEAR
      IDAST=IDATE(1,1,NEWYR)
      WRITE (IO,2000)
      IPRV=0
   10 CONTINUE
C
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   * *
C                CHECK IF NEXT BLOCK OF TAPE IS TO BE READ                  *
      IF (LREC9 .LT. 10) GO TO 11                                           *
C                READ A BLOCK OF TAPE                                       *
      CALL MAGTA (0,0,9LR,IBUF(2))                                          *
C                CONVERT TO IBM 1130 ARRAY CONVENTION                       *
```

```
      CALL EXFLW (1000,IBUF)                                           *
      WRITE (93'1) IBUF                                                *
      CALL UEOF                                                        *
      LOC99=1                                                          *
C             EACH BLOCK OF TAPE CONTAINS 10 RECORDS                   *
   11 CONTINUE                                                         *
      READ (99'LOC99,1000,END=200,ERR=80)STA,YEAR,MONTH,DAY,CARD,RAIN, *
     1                                 IYRA2,IMOA2,IDYA2               *
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   **
C             REPLACE ABOVE BY
C     READ (99,1000,END=200,ERR=80)STA,YEAR,MONTH,DAY,CARD,RAIN,
C    1                           IYRA2,IMOA2,IDYA2
C
      REREAD 1010,ICARD
C
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *
C             SWITCH 8 UP WILL CAUSE PROGRAM TO BRANCH TO END OF STATION*
C                  ROUTINE                                             *
      CALL DATSW(8,ISW8)                                               *
      IF (ISW8 .EQ. 1) GO TO 210                                       *
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   **
C
      IF (CARD .NE. 1.  .AND.  CARD .NE. 2.) GO TO 10
C             CHECK FOR 2 CONSECUTIVE CARD 1'S OR 2'S
      IF (CARD .NE. ILSTC) GO TO 14
C             PRINT LAST RECORD IF TWO CONSECUTIVE CARD 1
      IF (CARD .EQ. 1) WRITE (IO,2000) ISAVE,(INPUT(IOST),I=1,29),IAST
C             PRINT AN ASTERISK IF 2 CONSECUTIVE CARD 2'S
      IF (CARD .EQ. 2) WRITE (IO,2200) IAST
C          CHECK FOR SAME STATION
   14 DO 16 I=1,6
      IF (STA(I) .NE. PRESTI(I)) GO TO 17
   16 CONTINUE
C             SAME STATION
      GO TO 19
C             NEW STATION-COMPLETE THE SYNOPTIC DATA FILE FOR THE YEAR
C                  JUST CONCLUDED
   17 IALT=1
      GO TO 40
C             CHECK FOR SAME YEAR
   19 YEAR=YEAR+1900
      IF (IYEAR .EQ. NEWYR) GO TO 30
C             A NEW YEAR SIGNALS ALTERNATIVE 2
C
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   **
      IF (IYEAR .NE. NEWYR) LOC99=LOC99-1                              *
C     *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   **
C             REPLACE ABOVE BY
C     IF (IYEAR .NE. NEWYR) BACKSPACE 99
C
      IF (IYEAR .NE. NEWYR) IALT=2
      IF (IYEAR .NE. NEWYR) GO TO 40
      ILSTC=CARD
C     ADD TO THIS YEAR'S MATRIX.  FIND DAY NUMBER
      IDAY=IDATE(DAY,MONTH,YEAR)-IDAST
      YEAR=YEAR-1900
      IRNS=ICARD-11*12
      DO 20 I=1,12
      IHR=IHR+1
      INPHR(IDAY,IHR)=RAIN(I)
   20 CONTINUE
      INPHR(IDAY,25)=IMOAP
      INPHR(IDAY,26)=IDYAP
      INPHR(IDAY,27)=IYRAP
      IPRN=1
      ISAVE(7)=MONTH
      ISAVE(8)=DAY
      ISAVE(9)=YEAR
      DO 25 I=1,6
      ISAVE(I)=STA(I)
   25 CONTINUE
C             ONLY PRINT WHEN SECOND CARD IS READ
      IF (CARD .EQ. 1) GO TO 10
      IF (ISKIP .EQ. 0)
     *         WRITE (IO,2000) STA,MONTH,DAY,YEAR,(INPHR(IDAY,I),I=1,24)
      IPRN=0
      GO TO 10
   30 WRITE (IO,2020) ICARD
C             FORMAT ERROR OR ILLEGAL CARD CODE-JUST PRINT CARD
      GO TO 10
C
C             END OF YEAR OR END OF FILE-COMPUTE SYNOPTIC DATA
C
   40 WRITE (IO,2030)
C             SAVE LAST STORM NUMBER AND PRESENT FILE NUMBER
      NOLDS=STORM
      LOLDS=LOCSN
      NORSA=NORT
C             FIND NUMBER OF DAYS IN THIS YEAR
      NDAYS=IDATE(1,1,NEWYR+1)-IDATE(1,1,NEWYR)
      CALL SETIA (ICOND,17,22,0)
      NOYRS=NOYRS+1
      DO 100 J=1,NDAYS
      IDATE=IDATE(1,1,NEWYR)+J-1
      CALL DAIDA (IDATE,IROW,ICOL,IYR)
      IROW=IROW
      DO 90 K=1,24
      IF (INPHR(J,K) .EQ. 0) NCATS=1
      IF (INPHR(J,K) .NE. 0) NCATS=(INPHR(J,K)+11)/10
      IF (NCATS .GT. 20) NCATS=21
      ICOND(IROW,NCATS)=ICOND(IROW,NCATS)+1
C             PRESENT CONDITION IS DETERMINED IF ANY PRECIPITATION IS
C             RECORDED FOR THIS HOUR
      PRCON=2
      IF (INPHR(J,K) .GT. 0) PRCON=1
C             PREVIOUS CONDITION AND PRESENT CONDITION DETERMINE CURRENT
C             STATUS
      NEXT=(COND-1)*2+PRCON
C             PRCON  AND  COND  CAN BE EITHER 1 OR 2.  THUS  NEXT
C             WHICH DEFINES THE CURRENT STATUS CAN BE EITHER 1,2,3, OR 4
C             AS INDICATED IN THE FOLLOWING TABLE
C
C                        PREVIOUS CONDITION
C                          WET       DRY
```

```
C                         (COND=1)  (COND=2)
C     PRESENT       WET
C     CONDITION  (PRECON=1)     1         3
C
C                    DRY        2         4
C                 (PRECON=2)
C
      GO TO (50,60,70,80),NEXT
C              CONTINUE STORM (NEXT=1)
   50 DURAT=DURAT+1+NDRYH
      NDRYH=0
      VOLUM=VOLUM+INPUT(J,K+16,8)
      GO TO 90
C              DRY PERIOD (NEXT=2)--CHECK IF NO. OF CONSECUTIVE DRY HOURS
C              IS SUFFICIENT TO BE CONSIDERED AS END OF STORM
   60 NDRYH=NDRYH+1
      IF (NDRYH .LT. STMDF) GO TO 90
C              END OF STORM
      STORM=STORM+1
C              FOR FIRST STORM IN FILE ASSUME DURATION OF LAST STORM TO
C              BE THE SAME AS THE FIRST STORM
      IF (STORM .EQ. 1) DURLS=DURAT
      DELTA=0.5*(DURAT+DURLS)+FLOAT(NDRY)
      IF (STORM .EQ. 1) DELTA=0.
      VOLUM=VOLUM*0.000005
      INTEN=VOLUM/FLOAT(DURAT)
      WRITE (NPTLOCAL,2810) PREST,MSTRM,DSTRM,YSTRM,HSTRM,DURAT,INTEN,
     ,                       VOLUM,DELTA
      WRITE (10,2820) PREST,STORM,MSTRM,DSTRM,YSTRM,HSTRM,DURAT,INTEN,
     ,                       VOLUM,DELTA
      NDRY=NDRYH
      NDRYH=0
      COND=DRY
      DURLS=DURAT
      GO TO 90
C              BEGINNING OF STORM  (NEXT=3)
   70 MSTRM=INPUT(J,25)
      DSTRM=INPUT(J,26)
      YSTRM=INPUT(J,27)
      HSTRM=K
      DURAT=1
      VOLUM=INPUT(J,K+4,8)
      NDRYH=0
      COND=WET
      GO TO 90
C              CONTINUATION OF DRY WEATHER (NEXT=4)
   80 NDRY=NDRY+1
   90 CONTINUE
  100 CONTINUE
      WRITE (10,2830) (I,I=1,20),AVDST
      ISUM=0
      DO 9159 I=1,12
      DO 9159 J=1,21
      ICOUNT(13,J)=ICOUNT(13,J)+ICOUNT(I,J)
      ICOUNT(I,22)=ICOUNT(I,22)+ICOUNT(I,J)
      ISUM=ISUM+ICOUNT(I,J)
 9159 CONTINUE
```

```
      DO 9185 I=1,12
      WRITE (IO,2220)(ICOUN(I,J),J=1,22)
 9185 CONTINUE
      WRITE (IO,2220)(ICOUN(13,J),J=1,21)
      WRITE (IO,2185) ISUR
C             UPDATE FOR NEXT YEAR
      NEWYR=NEWYR+1
C             REVERT TO SAVED STORM AND RECORD NUMBER IF LESS THAN 2
C                   STORMS
      IF (ISTORM-NOLDS .GE. 2) GO TO 185
      NORT=NORSA
      ISTORM=NOLDS
      LOC9R=LOLDR
C             SUBTRACT NUMBER OF YEARS FOR RETURN PERIOD
      NOYRS=NOYRS-1
  185 CONTINUE
C             CHECK WHICH ALTERNATIVE HAS BEEN SELECTED
C             ALTERNATE 1=END OF STATION OR END OF TAPE MARKET
C             ALTERNATE 2=END OF YEAR ONLY
      GO TO (110,2),IALT
C             CHECK FOR DISMOUNTING PRESENT TAPE
C     *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  * *
  110 IF (IDISM .EQ. 1) CALL MAGTA(8,0)                                  *
C     *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  * *
C             REPLACE ABOVE BY
C 110 IF (IDISM .EQ. 1) REWIND 99
C
C
C     *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  * *
C             SWITCH 0 UP WILL CAUSE PROGRAM TO BRANCH TO END OF STATION*
C                   ROUTINE                                             *
      CALL DATSW(0,ISW0)                                                  *
      IF (ISW0 .EQ. 1) GO TO 210                                          *
C     *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  * *
C
C
C             CHECK FOR PAUSING FOR NEXT TAPE
      IF (IPAUS .EQ. 0) GO TO 210
      WRITE (ITYP,2190) TAPEN
      PAUSE 1111
      GO TO 1
C             REWIND TAPE AND GO TO SUMMARY
C
C
C     *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  * *
  200 CALL MAGTA (8,0)                                                    *
C     *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  * *
C             REPLACE ABOVE BY
C 200 REWIND 99
C
      IALT=1
      GO TO 90
C             READ SYNOPTIC FILE KEY FIELDS (MONTH AND YEAR)
C             WRITE EOF ON DISK
  210 WRITE (99'LOC9R,2850)
      LOC9R=1
      I=1
  220 READ (99'LOC9R,1850,END=250)(KEY(I,J),J=1,2)
      KEY(I,3)=I
      I=I+1
      GO TO 280
  230 NREC=I-1
C            FOR EACH KEY, OBTAIN STATISTICS
      DO 300 ICOL=1,2
      JR(1)=ICOL
      CALL SHELL (KEY,NREC,NROW,5,JR1,JR2)
      WRITE (IO,2070)((NAME(J,ICOL),J=1,5),I=1,2)
      KEYV=KEY(1,ICOL)
      NREC=NREC+1
      IC=0
      DO 235 J=1,9
      YMAX(J)=0.
      Y2MAX(J)=0.
  235 CONTINUE
      DO 300 J=1,NREC
      IF (J .EQ. 1) GO TO 260
      IF (J .EQ. NREC) GO TO 240
C            CHECK FOR CHANGE IN KEY
      IF (KEY(J,ICOL) .EQ. KEYV) GO TO 280
C            BREAK OCCURED
  240 IC=IC+1
      X(IC)=FLOAT(KEYV)
      DO 250 I=1,9
      STAT(I,5)=STAT(I,2)/STAT(I,1)
      STAT(I,6)=SQRT(ABS((STAT(I,3)-STAT(I,2)**2/STAT(I,1))/(STAT(I,1)-
     *           1.0)))
      STAT(I,7)=STAT(I,6)**2
      STAT(I,8)=STAT(I,6)/STAT(I,5)
C            SAVE MEAN AND STD DEV FOR EACH VARIABLE FOR PLOTTING
      ICNT=(I-1)*2+1
      Y(IC,ICNT)=STAT(I,5)
      Y(IC,ICNT+1)=STAT(I,6)
      IF (STAT(I,5) .GT. YMAX(I)) YMAX(I)=STAT(I,5)
      IF (STAT(I,6) .GT. YMAX(I)) YMAX(I)=STAT(I,6)
      IF (STAT(I,8) .GT. Y2MAX(I)) Y2MAX(I)=STAT(I,8)
  250 CONTINUE
      WRITE (IO,2130) KEYV
      DO 255 I=1,9
      WRITE (IO,2080) (TITLE(K,I),K=1,5),(STAT(I,M),M=1,8)
  255 CONTINUE
      KEYV=KEY(J,ICOL)
      IF (J .EQ. NREC) GO TO 300
  260 DO 270 I=1,9
      STAT(I,1)=0.
      STAT(I,2)=0.
      STAT(I,3)= 1.0E38
      STAT(I,4)=-1.0E38
      STAT(I,6)=0.
  270 CONTINUE
  280 IREC=KEY(J,5)
      READ (99'IREC,9010)RESVD
      DO 290 I=1,9
      DATA=RESVD(I)
      STAT(I,1)=STAT(I,1)+1.
      STAT(I,2)=STAT(I,2)+DATA
      IF (DATA .LT. STAT(I,3)) STAT(I,3)=DATA
      IF (DATA .GT. STAT(I,4)) STAT(I,4)=DATA
      STAT(I,5)=STAT(I,5)+DATA*DATA
  290 CONTINUE
  300 CONTINUE
      WRITE (IO,2090)(TITLE(J,ICOL),J=1,5),(I,I=1,2)
      DO 310 I=1,IT
      WRITE (IO,2120) X(I),(Y(I,J),J=1,N)
  310 CONTINUE
      YMIN=0.
      DO 320 L=1,N
      I=(L-1)*2+1
      DO 315 J=1,IT
      K=J*2-1
      PLOT(K,1)=X(J)
      PLOT(K,2)=Y(J,I)
      PLOT(K,3)=1.
      PLOT(K+1,1)=X(J)
      PLOT(K+1,2)=Y(J,I+1)
      PLOT(K+1,3)=20.
  315 CONTINUE
      NTOT=2*IT
      CALL SHLD(PLOT,NTOT,60,3,JW3,JW3)
      DO 318 J=1,NTOT
      ISYM(J)=IFIX(PLOT(J,3)+0.5)
  318 CONTINUE
      CALL CSADP(PLOT(1,1),PLOT(1,2),XMAX(ICOL),XMIN(ICOL),YMAX(L),YMIN,
     *           NTOT,1,50,SCALE(ICOL),0,0,0,ISYM)
      WRITE (IO,2100) (TITLE(M,L),M=1,5),(VAR(M,ICOL),M=1,8)
  320 CONTINUE
  400 CONTINUE
      DO 500 IVAR=1,9
      LOCNR=1
      K=1
C              READ VARIABLE
  410 READ (INT,REC=K,ERR=420)(X(J),J=1,9)
      XVAL(K,1)=X(IVAR)
      K=K+1
      GO TO 410
  420 NOCC=K-1
C              SORT BY VALUE
      CALL SHLD (XVAL,NOCC,2500,1,JW3,JW3)
      WRITE (IO,2180)((TITLE(J,IVAR),J=1,5),I=1,2)
C              COMPUTE PLOTTING POSITION
      DO 430 I=1,NOCC
      XVAL(I,2)=FLOAT(I)/FLOAT(NOCC+1)*100.
  430 CONTINUE
      WRITE (IO,2190)((XVAL(I,J),J=1,2),I=1,NOCC)
C              PLOT RESULTS
C              SORT FIRST COLUMN REVERSED
      CALL SHLD(XVAL,NOCC,2500,2,JW3,JW3)
      CALL CSADP(XVAL(1,2),XVAL(1,1),100.,0.,XMAX(IVAR),0.,NOCC,1,
     *           50,100,0,2,0,ISYM)
      WRITE (IO,2100) (TITLE(J,IVAR),J=1,5)
      WRITE (IO,2160)
C              COMPUTE RECURRENCE INTERVAL
      DO 440 I=1,NOCC
      XVAL(I,2)=FLOAT(NOYRS)/FLOAT(I)
  990 CONTINUE
      WRITE (IO,2120)(TITLE(J,IVAR),J=1,5)
      WRITE (IO,2150)((VALU (I,J),J=1,2),I=1,NOCCU)
      XSMAX=FLOAT(IYRS)
C           PLOT RESULTS
      CALL FSKIP(XVALU(1,2),XVALU(1,1),XSMAX,0.,YSMAX(IVAR),0.,NOCCU,1,
     *              50,100,0,2,0,ISYM)
      WRITE (IO,2155) (TITLE(J,IVAR),J=1,5)
      WRITE (IO,2160)
  500 CONTINUE
      GO TO 1
  999 CALL EXIT
 1000 FORMAT (6A1,3I2,I1,I2,I5,I2,5A2)
 1010 FORMAT (9A1)
 1020 FORMAT (3A2,I4,I1,5F5,3A2)
C
C     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0 0
 1025 FORMAT (6A1,3I2)                                                  0
C     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0 0
C
 1030 FORMAT (I2,I2,4X,I2)
 1050 FORMAT (25X,F5.0,4F10.3)
 2000 FORMAT ([illegible])
 2010 FORMAT ([illegible])
 2020 FORMAT ([illegible])
 2030 FORMAT (1H1,20X,'STORM EVENT SUMMARY'//
     *               ' STATION  STORM        DATE  HOUR DURAT   INTENSITY
     *,VOLUME       DELTA'/
     *               '                  NO                 HOURS   INCHES/HR
     *,INCHES       HOURS'/)
 2040 FORMAT (1H1,40X,'HYDROSCIENCE RAINFALL ANALYSIS PROGRAM'//
     *              40X,'HOURLY PRECIPITATION-HUNDREDTHS OF AN INCH'/
     *              '  STATION     DATE          1   2   3   4   5   6   7
     *,8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24'
     */)
 2050 FORMAT ('+')
 2060 FORMAT (' ',[illegible],'NO DATA IN RECORD')
 2070 FORMAT (1H1,[illegible],'RAINFALL STATISTICS BY ',3A2,' FOR PERIOD OF RECO
     *RD'/[illegible]/
     *              [illegible]'NUMBER',[illegible]'TOTAL',[illegible]'MINIMUM',[illegible]'MAXIMUM',
     *              [illegible]'AVERAGE',[illegible]'STD DEV',[illegible]'VARIANCE',[illegible]'COEF VAR')
 2080 FORMAT ([illegible])
 2090 FORMAT (1H1,[illegible],'SUMMARY OF RAINFALL STATISTICS BY ',3A2,' FOR PER
     *IOD OF RECORD'//
     *              [illegible]   [illegible],'DURATION',[illegible],'INTENSITY',[illegible],'VOLUME',[illegible]
     *,'DELTA'/[illegible]       [illegible]  AVERAGE   STD DEV')
 2100 FORMAT ([illegible],'AVERAGE', [illegible]STD, DEV')
 2110 FORMAT ([illegible])
 2120 FORMAT ([illegible])
 2130 FORMAT ([illegible])
 2135 FORMAT ('0 TOTAL HOURS FOR THE YEAR = ',I6)
 2140 FORMAT (1H1,[illegible],'PROBABILITY ANALYSIS',3A2//
     *              [illegible],'PERCENTAGE OF OCCURRENCE LESS THAN OR EQUAL TO TH
     *E GIVEN VALUE OF ',5A2//[illegible],'VALUE',[illegible],'PCT')
 2150 FORMAT ([illegible])
 2160 FORMAT (1H1,[illegible],'PERCENT LESS THAN OR EQUAL TO')
 2170 FORMAT (1H1,[illegible],'RETURN PERIOD (IN YEARS) FOR ',5A2///[illegible],'VAL
     ,UE',2X,'PERIOD')
0180 FORMAT (1H ,15X,'RETURN PERIOD IN YEARS')
0190 FORMAT (///' OPERATOR,MOUNT TAPE NO, ',8A2,' AND THEN PRESS START'
     ,)
0200 FORMAT (12I6,I2)
0210 FORMAT (///35X,'NUMBER OF HOURS OF RAINFALL IN HUNDREDTHS OF AN IN
     ,CH'/21X,'INTERVALS BETWEEN 0.00 AND 0.20 INCHES'/' MONTH    0',
     ,20I5,5X,'TOTAL'/153X,A2,1X,'HOURS'/115X,' PER'/115X,'MONTH')
0220 FORMAT (6X,21I5,I9,I2,I5)
     END
```

E.5 Example of Computer Output From Program SYNOP

The example output presented in this section demonstrates the application of program SYNOP for a rainfall analysis of U.S. Weather Bureau station 052220 in Denver, Colorado. This is the same data which is contained in the sample data set transmitted with copies of the program.

The program presents a complete summary of the rainfall history for each year of record. This includes an hourly percipitation history, a summary of each event's statistics, and a histogram of rainfall events for each month of the year. The sample output only presents this analysis for 1948 through 1950, and 1973.

The program then proceeds through a series of statistical summaries of the entire data record. These are:

Aggregate monthly rainfall statistics
Plots of rainfall statistics by month
Annual rainfall statistics
Plots of rainfall statistics by year
Probability analysis of rainfall statistics
Probability density function
Return period analysis

This output will serve as a check on program SYNOP. The program input is that on card 5 and 6 in Table E-1.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

HYDROSCIENCE RAINFALL ANALYSIS PROGRAM

STATION	DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
		HOURLY PRECIPAITATION-HUNDREDTHS OF AN INCH																							
052220	1/ 1/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	1/ 2/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	9	5	5	2	3	3	2	5
052220	1/ 3/49	1	1	1	1	1	1	2	1	1	2	1	1	2	1	1	2	1	1	1	1	1	1	2	0
052220	1/ 4/49	1	2	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
052220	1/ 8/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
052220	1/ 9/49	2	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	1/26/49	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	1/27/49	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1
052220	1/28/49	1	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	2/ 1/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	2/12/49	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0
052220	3/ 1/49	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	3/ 5/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	6	7	1	1	3
052220	3/ 6/49	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	3/ 8/49	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
052220	3/12/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	8	4	0	1	0	0
052220	3/14/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
052220	3/23/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
052220	3/24/49	5	6	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	3/25/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	9	0
052220	3/28/49	0	0	0	0	0	0	0	0	1	1	1	2	3	4	5	6	6	5	6	4	2	3	4	5
052220	3/29/49	7	8	9	7	9	1	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
052220	3/30/49	1	2	4	4	4	4	2	2	2	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
052220	4/ 1/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
052220	4/ 2/49	0	1	0	1	0	0	1	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
052220	4/ 3/49	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	4/ 8/49	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	9
052220	4/ 9/49	11	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	7	6	7	7	0
052220	4/10/49	0	0	0	2	1	0	0	2	1	4	2	0	0	1	0	0	0	0	0	0	0	0	0	0
052220	4/13/49	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	2	3	5	5
052220	4/14/49	3	1	0	0	1	0	0	0	3	2	2	1	0	1	0	0	0	0	0	0	0	0	0	0
052220	4/20/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3
052220	4/21/49	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	4/26/49	0	0	0	0	0	0	0	0	1	7	6	0	0	2	9	1	1	2	1	0	0	0	0	0
052220	4/30/49	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	5/ 1/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	5/ 5/49	0	0	1	0	0	0	0	6	4	2	5	5	4	6	3	1	4	5	4	2	1	1	2	3
052220	5/ 6/49	3	2	3	5	11	4	1	4	5	6	1	3	4	10	12	3	3	3	3	2	1	1	2	3
052220	5/ 7/49	2	3	5	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	5/11/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	4	1	1	0	2	18	7	0
052220	5/13/49	0	0	0	0	0	0	2	15	24	15	2	0	0	1	6	2	0	0	0	4	0	0	0	0
052220	5/15/49	0	0	8	1	2	0	0	0	0	0	0	0	0	5	1	1	0	5	1	0	0	0	0	0
052220	5/16/49	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	4	0
052220	5/18/49	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	1	1	0	0
052220	5/20/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
052220	5/21/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
052220	5/23/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
052220	5/27/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
052220	5/28/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
052220	6/ 1/49	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
052220	6/ 2/49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	11	3	7
052220	6/ 3/49	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	14	10	27	29	17

```
052220  6/ 4/49    19   3   5   3   5   8   3   2   6   1  16   1   2   1   0   0   2   6   0   0   1   2   2   2
052220  6/ 5/49     3   1   2   1   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220  6/ 6/49     0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   1   0   0   0   0  10   3   4
052220  6/ 7/49     1   1   0   0   1   0   2   8   5   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220  6/ 8/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   9   3   2   1   0   0   0   1   0   0
052220  6/12/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   7   2   2   4   6
052220  6/13/49     2   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   1   0   0   0   0   0  11  23
052220  6/14/49     3   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220  6/17/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0
052220  6/18/49     0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0
052220  6/23/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  35  24   1   0   0   0
052220  6/26/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2  11   0   0   0   0   0   0
052220  6/27/49     0   0   0   0   0   0   0   0   0   0   0   4   0   0   0   0   1   1   0   0   0   0   0   0
052220  6/28/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0
052220  7/ 1/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   4   3   0   0   0   0   0   0   0
052220  7/ 3/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   3   0   0   0   0   0   0   0
052220  7/ 5/49     0   0   0   0   0   0   0   0   0   0   0   0   0  47   4   0   0   2   0   0   0   0   0   0
052220  7/ 6/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2   0   0   0   5   0   0   0
052220  7/ 7/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0
052220  7/ 8/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   1   0   0   0   0   0   0
052220  7/11/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  20   0   0   0   0   0   0   0   0
052220  7/13/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   1   1   2   0   0   0   0
052220  7/14/49     0   0   1   0   0   0   0   0   0   0   0   0   0   0   5   1   0   0   0   0   0   0   0   0
052220  7/18/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   3   1
052220  7/21/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0
052220  7/24/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   3   1   4   3
052220  7/25/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2   0   0   0   0   0   0   0   0
052220  7/28/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   1   5
052220  7/29/49     3   1   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220  8/ 1/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220  8/ 3/49     0   0   0   0   0   2   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220  8/ 8/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  18   3   0   0   0   0   0   0
052220  8/ 9/49     0   0   0   0   0   0   0   0   0   0   0   0   0  14   3   0   0   0   0   0   0   0   0   0
052220  8/11/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2   0   0   0   0   0   0   0   0
052220  8/12/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   1
052220  8/13/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   7   0   0   0   0   0   0   0   0   0
052220  8/14/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   5   0
052220  8/17/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   2   2   0   0   0   0   0   0   0   0
052220  8/19/49     0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0
052220  8/24/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   6  12   6   2   0
052220  8/25/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0
052220  8/29/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2   0
052220  9/ 1/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220  9/ 3/49     0   0   0   0   0   0   0   2   0   0   0   0   0   0  11   1   0   0   0   0   0   0   0   0
052220  9/30/49     0   0   0   0   0   0   0   0   0   9   3   0   1   1   0   0   0   0   0   0   0   0   0   0
052220 10/ 1/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220 10/ 8/49     0   0   0   0   1   0   0   0   0   0   1   0   1   1   2   2   1   1   1   1   3   2   2   4
052220 10/ 9/49     0   1   1   1   1   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0  11   1   0   0
052220 10/18/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  14   0   0   0   0   0
052220 10/19/49     0   0   0   0   0   0   1   0   1   1   1   0   0   0   1   0   0   4  11   4   7   8   4   1
052220 10/20/49     0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220 10/29/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2   3   1   1   1   4   1   5  10
052220 10/30/49     4   1   1   1   2   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220 11/ 1/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220 11/11/49     0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220 12/ 1/49     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220 12/11/49     4   3   3   3   3   2   3   4   3   2   1   0   0   0   0   0   0   0   0   0   0   0   0   0
052220 12/20/49     0   0   0   0   1   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
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                        STORM EVENT SUMMARY
STATION  STORM       DATE  HOUR DURAT   INTENSITY    VOLUME       DELTA
            NO                  HOURS   INCHES/HR    INCHES       HOURS

 052220     25  01/02/49    15     49    0.017347      0.85       159.0
 052220     26  01/08/49    23     10    0.010000      0.10       132.5
 052220     27  01/23/49    10      1    0.010005      0.01       342.5
 052220     28  01/27/49     8      4    0.010001      0.04        95.5
 052220     29  01/27/49    19     16    0.010625      0.17        17.0
 052220     30  02/12/49    12      2    0.010002      0.02       370.0
 052220     31  02/12/49    18      1    0.010005      0.01         5.5
 052220     32  03/01/49     1      3    0.026668      0.08       392.0
 052220     33  03/05/49    19      7    0.035714      0.25       116.0
 052220     34  03/08/49     1      4    0.007501      0.03        52.5
 052220     35  03/08/49    20      1    0.010005      0.01        17.5
 052220     36  03/12/49    18      5    0.054000      0.27        96.0
 052220     37  03/14/49    17      1    0.010005      0.01        45.0
 052220     38  03/23/49    21      8    0.025000      0.20       223.5
 052220     39  03/25/49    21      3    0.046668      0.14        45.5
 052220     40  03/28/49     9     25    0.040400      1.01        71.0
 052220     41  03/29/49    19      1    0.010005      0.01        22.0
 052220     42  03/30/49     1     13    0.021538      0.28        12.0
 052220     43  04/01/49    23     11    0.006364      0.07        69.0
 052220     44  04/02/49    13      1    0.010005      0.01         9.0
 052220     45  04/03/49     8      3    0.006668      0.02        20.0
 052220     46  04/08/49    10      4    0.007501      0.03       122.5
 052220     47  04/08/49    23      4    0.057501      0.23        13.0
 052220     48  04/09/49    10      1    0.010005      0.01         9.5
 052220     49  04/09/49    19      5    0.056000      0.28        11.0
 052220     50  04/10/49     4     11    0.011818      0.13        12.0
 052220     51  04/13/49    11      1    0.030005      0.03        74.0
 052220     52  04/13/49    21      9    0.022222      0.20        14.0
 052220     53  04/14/49     9      6    0.015000      0.09        10.5
 052220     54  04/20/49    17      1    0.010005      0.01       149.5
 052220     55  04/20/49    24      2    0.020002      0.04         7.5
 052220     56  04/26/49     9     11    0.027273      0.30       133.5
 052220     57  04/30/49     7      1    0.010005      0.01        89.0
 052220     58  05/05/49     3      1    0.010005      0.01       116.0
 052220     59  05/05/49     8     46    0.037826      1.74        27.5
 052220     60  05/11/49    15      9    0.041111      0.37       132.5
 052220     61  05/13/49     7     10    0.067000      0.67        40.5
 052220     62  05/13/49    20      1    0.040005      0.04         8.5
 052220     63  05/15/49     3      3    0.036668      0.11        32.0
 052220     64  05/15/49    14      6    0.021667      0.13        12.5
 052220     65  05/16/49    13      2    0.010002      0.02        21.0
 052220     66  05/16/49    22      2    0.025002      0.05         9.0
 052220     67  05/18/49    13      1    0.050005      0.05        38.5
 052220     68  05/18/49    21      2    0.010002      0.02         8.5
 052220     69  05/20/49    15      2    0.010002      0.02        42.0
 052220     70  05/21/49    19      2    0.010002      0.02        28.0
 052220     71  05/23/49    17      1    0.030005      0.03        45.5
 052220     72  05/27/49    18      1    0.020005      0.02        97.0
 052220     73  05/28/49    15      1    0.010005      0.01        21.0
 052220     74  06/01/49    12      1    0.010005      0.01        93.0
 052220     75  06/02/49    20      7    0.044286      0.31        35.0
 052220     76  06/03/49    19     35    0.056000      1.96        37.0
 052220     77  06/06/49     7      1    0.010005      0.01        43.0
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052220    78  06/06/49    17     1    0.010005     0.01       10.0
052220    79  06/06/49    22    13    0.027692     0.35       11.0
052220    80  06/08/49    15     4    0.037501     0.15       36.5
052220    81  06/08/49    22     1    0.010005     0.01        5.5
052220    82  06/12/49    19     7    0.034286     0.24       95.0
052220    83  06/13/49    15     3    0.006668     0.02       18.0
052220    84  06/13/49    23     3    0.123334     0.37        8.0
052220    85  06/17/49    15     1    0.010005     0.01       88.0
052220    86  06/18/49    14     1    0.010005     0.01       22.0
052220    87  06/23/49    19     3    0.200001     0.60      126.0
052220    88  06/26/49    17     2    0.065002     0.13       69.5
052220    89  06/27/49    12     1    0.040005     0.04       18.5
052220    90  06/27/49    17     2    0.010002     0.02        5.5
052220    91  06/28/49    15     1    0.010005     0.01       21.5
052220    92  07/01/49    16     2    0.035002     0.07       73.5
052220    93  07/03/49    17     1    0.030005     0.03       48.5
052220    94  07/05/49    14     5    0.106000     0.53       47.0
052220    95  07/06/49    17     1    0.020005     0.02       25.0
052220    96  07/06/49    21     1    0.050005     0.05        4.0
052220    97  07/07/49    20     1    0.010005     0.01       23.0
052220    98  07/08/49    17     2    0.010002     0.02       21.5
052220    99  07/11/49    15     1    0.200004     0.20       70.5
052220   100  07/13/49    17     4    0.012501     0.05       50.5
052220   101  07/14/49     3     1    0.010005     0.01        8.5
052220   102  07/14/49    15     2    0.030002     0.06       12.5
052220   103  07/18/49    23     2    0.020002     0.04      104.0
052220   104  07/21/49    16     1    0.010005     0.01       64.5
052220   105  07/24/49    21     4    0.027501     0.11       78.5
052220   106  07/25/49    15     1    0.020005     0.02       17.5
052220   107  07/28/49    19     1    0.010005     0.01       75.0
052220   108  07/28/49    23     5    0.022000     0.11        6.0
052220   109  08/03/49     5     2    0.015002     0.03      125.5
052220   110  08/05/49    17     2    0.105002     0.21      131.0
052220   111  08/09/49    14     2    0.085002     0.17       21.0
052220   112  08/11/49    16     1    0.020005     0.02       49.5
052220   113  08/12/49    23     2    0.010002     0.02       31.5
052220   114  08/13/49    15     1    0.070004     0.07       15.5
052220   115  08/14/49    23     1    0.050005     0.05       32.0
052220   116  08/17/49    15     2    0.020002     0.04       64.5
052220   117  08/19/49    11     1    0.010005     0.01       43.5
052220   118  08/24/49    19     5    0.054000     0.27      130.0
052220   119  08/25/49    17     1    0.010005     0.01       20.0
052220   120  08/29/49    23     1    0.020005     0.02      102.0
052220   121  09/03/49     8     1    0.020005     0.02      105.0
052220   122  09/03/49    15     2    0.060002     0.12        7.5
052220   123  09/30/49    10     5    0.028000     0.14      644.5
052220   124  10/08/49     5     1    0.010005     0.01      185.0
052220   125  10/08/49    11    19    0.013684     0.25       15.0
052220   126  10/09/49    15     1    0.010005     0.01       20.0
052220   127  10/09/49    21     2    0.060002     0.12        5.5
052220   128  10/18/49    19     1    0.140004     0.14      213.5
052220   129  10/19/49     7     5    0.008000     0.04       14.0
052220   130  10/19/49    15    13    0.031538     0.41       12.0
052220   131  10/29/49    16    14    0.026428     0.37      241.5
052220   132  11/11/49     9     1    0.010005     0.01      298.5
052220   133  12/11/49     1    11    0.028182     0.31      717.0
052220   134  12/20/49     5     1    0.010005     0.01      215.0
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052220    135  12/20/49     9     1    0.010005      0.01          4.0


                                    NUMBER OF HOURS OF RAINFALL IN HUNDREDTHS OF AN INCH
                                          INTERVALS BETWEEN 0.00 AND 0.20 INCHES
MONTH     0     1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20    TOTAL
                                                                                                                                 &>    HOURS
                                                                                                                                         PER
                                                                                                                                       MONTH
    1   669    56    12     2     0     3     0     1     0     1     0     0     0     0     0     0     0     0     0     0     0      744
    2   669     3     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      672
    3   679    22     9     5     9     6     5     3     2     3     0     0     0     0     1     0     0     0     0     0     0      744
    4   665    29    10     5     1     2     2     4     0     2     0     1     0     0     0     0     0     0     0     0     0      720
    5   658    26    15    12    10     9     4     1     1     0     2     1     1     0     0     2     0     0     1     0     1      744
    6   641    29    13     8     3     3     3     3     2     1     2     3     0     0     1     0     1     1     0     1     5      720
    7   711    15     4     5     3     3     0     0     0     0     0     0     0     0     0     0     0     0     0     0     2      744
    8   723     6     6     2     0     1     2     1     0     0     0     0     1     0     1     0     0     0     1     0     0      744
    9   713     3     1     1     0     0     0     0     0     1     0     1     0     0     0     0     0     0     0     0     0      720
   10   695    28     6     2     6     1     0     1     1     0     1     2     0     0     1     0     0     0     0     0     0      744
   11   719     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      720
   12   731     3     2     6     2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0      744
       8273   220    78    49    34    28    16    14     6     9     5     8     2     0     4     2     1     1     2     1     8

TOTAL HOURS FOR THE YEAR =   8760
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                                    HYDROSCIENCE RAINFALL ANALYSIS PROGRAM

                                          HOURLY PRECIPAITATION-HUNDREDTHS OF AN INCH
TION    DATE       1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24

2220   1/ 1/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   1/ 2/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0
2220   1/ 3/50     0   1   0   0   1   0   0   1   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0
2220   1/14/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2
2220   1/24/50     0   0   1   2   6   5   7   5   4   2   1   0   0   0   0   0   0   0   0   0   0   1   1   1
2220   1/25/50     1   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   1/29/50     0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   1/30/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0
2220   2/ 1/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   2/ 7/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   3   1   3   0
2220   2/ 8/50     0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   2/11/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1
2220   2/12/50     2   1   1   1   1   1   1   0   2   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   2/28/50     0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0
2220   3/ 1/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   3/11/50     0   0   0   0   0   0   0   0   0   1   0   0   1   0   0   0   1   2   2   1   2   2   1   1
2220   3/12/50     1   1   2   2   4   2   1   1   1   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0
2220   3/18/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0
2220   4/ 1/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   4/ 3/50     0   2   0   0   4   2   2   2   0   0   0   0   0   0   1   1   1   1   1   1   1   0   0   0
2220   4/ 4/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0
2220   4/15/50     0   0   0   0   0   0   0   0   0   0   0   0   1  21   7   8  22  13   8  55  42   1   2   0
2220   4/16/50     2   2   4   7   7   0   2   9   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   4/18/50     0   0   0   0   8   3   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   4/19/50     0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   4/28/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2  11   6   5   3  11   6
2220   4/29/50     4   4   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   5/ 1/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   5/ 4/50     0   0   0   1   1   0   1   0   0   0   0   1   2   2   2   3   7   3   4   3   4   3   7   3
2220   5/ 5/50     2   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   5/ 7/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   3   3   2   2   1   1   0   0   1
2220   5/ 9/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  11  14   8   5   2   0
2220   5/10/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   3   5   0
2220   5/15/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0
2220   5/25/50     0   3   2   2   3   4   4   4   5   5   7  11  11  10  10   8   8   5   5   5   4   5   5   3
2220   5/26/50     4   4   3   3   3   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   5/27/50     0   0   0   0   0   0   0   0   0   0   0   2   2   0   0   0   0   0   0   0   0   0   0   0
2220   5/28/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  13   0   0   0   0   0   0   0
2220   6/ 1/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2220   6/ 2/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2   2   7   5   4
2220   6/ 3/50     1   0   1   0   0   2   5   4   4   5   4   4   0   2   1   0   0   0   0   0   0   0   0   0
32220  6/16/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  82  46  57   4  17   0   0   0
32220  6/18/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  57   5   5
32220  6/19/50     3   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
32220  6/29/50     0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
32220  7/ 1/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  10   1   0   0   0   0
32220  7/ 2/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   3   0   0   0   0   0   0   0   0   0
32220  7/ 4/50     0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0
32220  7/ 5/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   3   0   0   0   0   0   0
32220  7/16/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0
32220  7/17/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   4   1   0   0   0   0   0   0
32220  7/18/50     0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   6   0   0   0   0
```

052220	7/29/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	6	0	0	0	0
052220	8/ 1/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	8/11/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0
052220	8/13/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	0	0	0	0
052220	8/16/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
052220	8/26/50	0	0	0	0	0	0	0	0	0	0	0	6	3	0	0	0	0	0	0	0	0	0	0	0
052220	8/27/50	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	9/ 1/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	9/ 8/50	0	0	0	0	0	0	0	0	0	45	10	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	9/ 9/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
052220	9/10/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	11
052220	9/11/50	23	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	0	0	2	0
052220	9/12/50	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	9/15/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
052220	9/16/50	1	0	1	0	1	0	0	0	0	0	0	0	0	0	6	2	0	0	0	0	0	0	0	0
052220	9/19/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	23	1	0	0	0	0	0	0
052220	10/ 1/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0	2	1	2	0	0
052220	11/ 1/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	11/ 2/50	0	0	0	0	0	0	0	0	3	1	8	4	2	0	0	0	0	0	0	0	0	1	1	0
052220	11/ 3/50	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	11/ 8/50	0	0	0	0	0	0	0	2	4	4	3	3	3	3	6	9	6	3	3	2	2	1	1	0
052220	11/ 9/50	2	2	3	4	3	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	11/19/50	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	12/ 1/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	12/ 4/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	1	1	0	1	1
052220	12/ 5/50	6	5	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	12/31/50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1

```
                           STORM EVENT SUMMARY
STATION  STORM      DATE  HOUR DURAT   INTENSITY    VOLUME      DELTA
            NO                 HOURS  INCHES/HR    INCHES      HOURS

 052220    136  01/02/50    23    10    0.004000     0.04      330.5
 052220    137  01/03/50    15     1    0.010005     0.01       11.5
 052220    138  01/14/50    24     1    0.020005     0.02      273.0
 052220    139  01/24/50     3     9    0.036667     0.33      223.0
 052220    140  01/24/50    22     5    0.010000     0.05       17.0
 052220    141  01/29/50     9     1    0.010005     0.01      105.0
 052220    142  01/30/50    21     1    0.010005     0.01       35.0
 052220    143  02/07/50    21     6    0.013334     0.08      194.5
 052220    144  02/11/50    24    10    0.011000     0.11      101.0
 052220    145  02/28/50    12     1    0.010005     0.01      391.5
 052220    146  03/11/50    10     4    0.005001     0.02      263.5
 052220    147  03/11/50    17    20    0.014000     0.28       15.0
 052220    148  03/18/50    15     1    0.010005     0.01      156.5
 052220    149  04/03/50     2     7    0.017143     0.12      374.0
 052220    150  04/03/50    15     7    0.010000     0.07       13.0
 052220    151  04/04/50    23     1    0.010005     0.01       29.0
 052220    152  04/15/50    13    20    0.106500     2.13      263.5
 052220    153  04/18/50     5     2    0.055002     0.11       55.0
 052220    154  04/19/50     4     1    0.010005     0.01       22.5
 052220    155  04/28/50    19    12    0.044167     0.53      235.5
 052220    156  05/04/50     4     4    0.007501     0.03      126.0
 052220    157  05/04/50    12    15    0.031333     0.47       13.5
 052220    158  05/07/50    16     9    0.014444     0.13       73.0
 052220    159  05/09/50    19     5    0.080000     0.40       49.0
 052220    160  05/10/50    22     2    0.050002     0.10       25.5
 052220    161  05/15/50    19     1    0.010005     0.01      116.5
 052220    162  05/25/50     2    29    0.051379     1.49      237.0
 052220    163  05/27/50    12     2    0.020002     0.04       44.5
 052220    164  05/28/50    17     1    0.130005     0.13       29.5
 052220    165  06/02/50    20    20    0.027000     0.54      132.5
 052220    166  06/16/50    17     5    0.412000     2.06      325.5
 052220    167  06/18/50    22     5    0.142000     0.71       53.0
 052220    168  06/29/50     5     1    0.010005     0.01      245.0
 052220    169  07/01/50    19     2    0.055002     0.11       62.5
 052220    170  07/02/50    15     1    0.030005     0.03       19.5
 052220    171  07/04/50    13     1    0.010005     0.01       46.0
 052220    172  07/05/50    17     2    0.020002     0.04       28.5
 052220    173  07/16/50    15     1    0.010005     0.01      261.5
 052220    174  07/17/50    17     2    0.025002     0.05       26.5
 052220    175  07/18/50    19     2    0.035002     0.07       26.0
 052220    176  07/29/50    19     2    0.120002     0.24      240.0
 052220    177  08/11/50    20     1    0.100005     0.10      336.5
 052220    178  08/13/50    16     5    0.008001     0.04       46.0
 052220    179  08/16/50    18     1    0.010005     0.01       72.0
 052220    180  08/26/50    12     2    0.045002     0.09      234.5
 052220    181  08/27/50     3     3    0.010001     0.03       15.5
 052220    182  09/08/50    10     2    0.280002     0.55      294.5
 052220    183  09/09/50    17     1    0.010005     0.01       30.5
 052220    184  09/10/50    17     2    0.010002     0.02       24.5
 052220    185  09/10/50    23     4    0.095001     0.38        7.0
 052220    186  09/11/50    18     6    0.015000     0.09       20.0
 052220    187  09/12/50     6     1    0.010005     0.01        9.5
 052220    188  09/15/50    21     9    0.005556     0.05       91.0
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052220     189  09/16/50     15     2    0.040002     0.08       14.5
052220     190  09/19/50     16     3    0.126668     0.38       73.5
052220     191  10/01/50     17     6    0.020000     0.12      290.5
052220     192  11/02/50      9     5    0.036000     0.18      759.5
052220     193  11/02/50     22     4    0.007501     0.03       12.5
052220     194  11/08/50      9    25    0.029600     0.74      100.5
052220     195  11/19/50     11     1    0.050005     0.05      255.0
052220     196  12/04/50     18    11    0.024545     0.27      372.0


                              NUMBER OF HOURS OF RAINFALL IN HUNDREDTHS OF AN INCH
                                    INTERVALS BETWEEN 0.00 AND 0.20 INCHES
MONTH     0    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20    TOTAL
                                                                                                          =>    HOURS
                                                                                                                  PER
                                                                                                                MONTH
   1    722   14    3    0    1    2    1    1    0    0    0    0    0    0    0    0    0    0    0    0    0     744
   2    658   10    2    2    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     672
   3    723   13    7    0    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     744
   4    676   12    9    2    4    1    2    3    3    1    0    2    0    1    0    0    0    0    0    0    4     720
   5    679   10   11   13    8    8    2    3    3    0    2    3    0    1    1    0    0    0    0    0    0     744
   6    693    5    4    1    6    4    1    1    0    0    0    0    0    0    0    0    0    1    0    0    4     720
   7    731    6    0    2    1    0    2    0    0    0    1    0    0    0    0    0    0    0    1    0    0     744
   8    735    4    2    1    0    0    1    0    0    0    1    0    0    0    0    0    0    0    0    0    0     744
   9    696   12    3    1    1    0    1    0    0    0    1    1    0    0    1    0    0    0    0    0    3     720
  10    739    1    3    0    0    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0     744
  11    687    7    8    9    4    1    2    0    1    1    0    0    0    0    0    0    0    0    0    0    0     720
  12    731    7    0    3    0    2    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0     744
       8470  101   52   34   26   19   13    8    7    2    5    6    0    2    2    0    0    1    1    0   11

TOTAL HOURS FOR THE YEAR =    8760
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BREAK:
SAME PROCEEDURE IS REPEATED
FOR 1951 - 1972

```
                                   HYDROSCIENCE RAINFALL ANALYSIS PROGRAM

                                                HOURLY PRECIPAITATION-HUNDREDTHS OF AN INCH
STATION    DATE        1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24

052220   1/ 1/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   1/ 3/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   1   0   0   0
052220   1/ 7/73       1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   1/ 8/73       0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0
052220   1/ 9/73       0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   1/20/73       0   0   0   0   4   7   8   7   9   9   7   4   5   4   4   4   6   1   1   1   2   1   2   1
052220   1/21/73       0   0   1   3   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   1/26/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   1   2   3   0
052220   1/27/73       1   1   1   1   1   3   4   4   6   4   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   2/ 1/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   2/ 7/73       0   0   0   0   0   0   0   0   0   1   1   1   0   0   0   0   0   0   0   0   0   0   0   0
052220   2/13/73       0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   2/18/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   4   6
052220   2/19/73       2   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   3/ 1/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   3/ 2/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2   4
052220   3/ 3/73       5   7   4   2   3   1   1   2   2   3   2   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   3/13/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   8   6   0   0   0   0   0   0   0
052220   3/14/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0
052220   3/15/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0
052220   3/18/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   5  20   7   7  10   8
052220   3/19/73       2   3   1   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   3/21/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   3   3   1   0
052220   3/24/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   1   2
052220   3/25/73       4   4   4   4   3   1   1   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   3/27/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   1   2   0
052220   3/28/73       0   1   1   0   3   1   1   1   1   0   0   1   0   0   0   0   0   0   0   0   0   0   1   0
052220   3/29/73       1   1   1   0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0
052220   3/30/73       0   0   0   0   0   0   2   1   0   0   0   0   2   0   0   0   0   0   0   0   0   0   0   0
052220   4/ 1/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   2   2
052220   4/ 2/73       1   0   0   0   1   0   2   2   0   1   4   5   5   3   0   1   2   6   3   2   0   0   1   2
052220   4/ 3/73       3   8   1   1   4   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   4/ 6/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   1   7
052220   4/ 7/73       2   4   2   2   1   4   4   3   8   6   5   3   3   4   3   5   2   4   6   4   4   4   4   3
052220   4/ 8/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   2   1   0
052220   4/15/73       0   0   0   0   1   0   0   0   0   1   2   1   2   2   2   1   1   1   0   0   0   0   0   0
052220   4/19/73       0   1   0   1   2   2   2   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0
052220   4/21/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0
052220   4/24/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   4   1   0   0   0   0   8  16  11   9
052220   4/25/73      10   9   2   2   3   8   5   5   1   2   2   0   0   1   0   0   0   0   0   0   0   0   0   1
052220   4/26/73       1   1   1   1   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   4/30/73       0   0   0   0   1   0   0   0   0   0   1   0   0   1   1   6  15  20   4   9  10   7   2   3
052220   5/ 1/73       0   1   0   0   0   0   1   1   0   0   1   0   0   0   0   0   0   0   0   0   0   0   3   2
052220   5/ 2/73       0   0   0   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   5/ 5/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0  16  12
052220   5/ 6/73       1   4   9   4  16  36  28  14  16  27  14  23  23  24  25  22  13  14  12   2   1   0   0   0
052220   5/19/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   4   0   0   0   0   0   0   0
052220   5/21/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   4   0   0   0   0   4
052220   5/22/73       7   6   5   1   2   2   2   3   3   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0
052220   5/24/73       0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   1   4   4   1   0   0
052220   5/26/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   1   0   0   0   0   0   0   0   0   0
052220   5/29/73       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   3   2   4
```

052220	5/30/73	6	6	10	16	4	6	6	7	7	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	6/ 1/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
052220	6/ 3/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	2	1	0	0	0	0
052220	6/ 4/73	0	0	0	0	0	0	0	0	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	6/12/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
052220	6/14/73	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
052220	7/ 1/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	7/ 9/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0
052220	7/12/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	13	6	1	0	0	0
052220	7/13/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
052220	7/14/73	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	7/15/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0
052220	7/16/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
052220	7/18/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
052220	7/19/73	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	53	0	0	0	0
052220	7/20/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
052220	7/21/73	0	0	0	1	0	0	0	0	0	0	0	0	6	3	0	0	0	0	0	0	0	0	0	0
052220	7/22/73	0	0	0	0	0	0	0	0	0	0	0	0	13	0	6	0	0	0	0	0	0	0	0	0
052220	7/23/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
052220	7/24/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	76	28	1	0	0	0	0
052220	7/30/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	0	3	0	0	0	0	0
052220	7/31/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
052220	8/ 1/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	8/ 5/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
052220	8/ 6/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
052220	8/ 7/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94	1	0	0	0	0	0	0	0
052220	8/11/73	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
052220	8/21/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0
052220	8/24/73	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0
052220	8/28/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
052220	8/31/73	0	0	0	0	0	0	1	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	9/ 1/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	9/ 2/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
052220	9/ 8/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0
052220	9/ 9/73	0	4	4	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	8	6	0	0	0	0
052220	9/10/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
052220	9/11/73	0	0	0	0	50	4	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	1
052220	9/15/73	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
052220	9/16/73	0	0	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0
052220	9/25/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
052220	9/26/73	3	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	9/27/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
052220	9/28/73	0	1	2	4	7	4	4	15	15	12	14	13	7	6	2	3	6	3	5	4	2	2	8	5
052220	9/29/73	5	2	1	1	1	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	10/ 1/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	10/ 3/73	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
052220	10/ 9/73	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	1	0	0	0
052220	10/10/73	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	2
052220	10/11/73	0	0	3	6	6	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	10/29/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	2
052220	10/30/73	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	11/ 1/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3
052220	11/ 2/73	3	3	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
052220	11/ 3/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
052220	11/ 4/73	0	2	0	2	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
052220	11/19/73	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2	5	3	3	4	9	6	2
052220	11/26/73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	3	0	0

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052220 11/27/73        0    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
052220 12/ 1/73        0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
052220 12/ 2/73        0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    2    7    4    4    4    3
052220 12/ 3/73       16   15    8    8    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
052220 12/18/73        0    0    0    0    0    0    1    2    5    5    4    4    4    4    2    2    2    5    7    2    5    3    2    1
052220 12/23/73        0    0    0    0    0    0    0    0    0    0    0    0    2    8   20    7    8    5   10   10   16   17   17    3
052220 12/24/73        1    2    4    6    1    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
052220 12/25/73        0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1
052220 12/26/73        0    1    2    2    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
052220 12/29/73        0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    1    1    1    0
052220 12/30/73        0    0    0    0    0    0    0    0    0    0    0    0    1    2    0    0    0    1    0    1    0    1    0    0
```

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                          STORM EVENT SUMMARY
STATION  STORM        DATE  HOUR DURAT   INTENSITY    VOLUME       DELTA
           NO                    HOURS   INCHES/HR    INCHES       HOURS

 052220   2238   01/03/73    15     1    0.010005      0.01        107.0
 052220   2239   01/03/73    21     1    0.010005      0.01          6.0
 052220   2240   01/07/73     1     1    0.010005      0.01         76.0
 052220   2241   01/08/73     6     1    0.010005      0.01         29.0
 052220   2242   01/08/73    23     1    0.010005      0.01         17.0
 052220   2243   01/09/73     5     1    0.010005      0.01          6.0
 052220   2244   01/20/73     5    25    0.036800      0.92        276.0
 052220   2245   01/26/73    20    15    0.022000      0.33        154.0
 052220   2246   02/07/73    10     3    0.010001      0.03        272.0
 052220   2247   02/13/73    11     1    0.010005      0.01        144.0
 052220   2248   02/18/73    23     3    0.040001      0.12        133.0
 052220   2249   03/02/73    23    13    0.029231      0.38        293.0
 052220   2250   03/13/73    15     2    0.070002      0.14        251.5
 052220   2251   03/14/73    23     1    0.010005      0.01         30.5
 052220   2252   03/15/73    16     1    0.010005      0.01         17.0
 052220   2253   03/18/73    19    12    0.053333      0.64         80.5
 052220   2254   03/21/73    21     3    0.023334      0.07         69.5
 052220   2255   03/24/73    22    12    0.021667      0.26         77.5
 052220   2256   03/27/73    20    17    0.008235      0.14         72.5
 052220   2257   03/28/73    23     5    0.008000      0.04         21.0
 052220   2258   03/29/73     7     1    0.010005      0.01          6.0
 052220   2259   03/29/73    22     1    0.010005      0.01         15.0
 052220   2260   03/30/73     7     2    0.015002      0.03          9.5
 052220   2261   03/30/73    13     1    0.020005      0.02          5.5
 052220   2262   04/01/73    23     3    0.016668      0.05         59.0
 052220   2263   04/02/73     5    25    0.022800      0.57         17.0
 052220   2264   04/06/73    22    27    0.036666      0.99        114.0
 052220   2265   04/08/73    21     3    0.013334      0.04         35.0
 052220   2266   04/15/73     5     1    0.010005      0.01        151.0
 052220   2267   04/15/73    10     9    0.014444      0.13          9.0
 052220   2268   04/19/73     2     6    0.013334      0.08         86.5
 052220   2269   04/19/73    15     1    0.010005      0.01         10.5
 052220   2270   04/21/73    16     1    0.010005      0.01         49.0
 052220   2271   04/24/73    15     2    0.025002      0.05         71.5
 052220   2272   04/24/73    21    18    0.052222      0.94         14.0
 052220   2273   04/25/73    24     7    0.008572      0.06         21.5
 052220   2274   04/30/73     5     1    0.010005      0.01         98.0
 052220   2275   04/30/73    11    16    0.049375      0.79         13.5
 052220   2276   05/01/73     7     5    0.006001      0.03         14.5
 052220   2277   05/01/73    23     2    0.025002      0.05         14.5
 052220   2278   05/02/73     4     1    0.010005      0.01          4.5
 052220   2279   05/05/73    16     1    0.010005      0.01         86.0
 052220   2280   05/05/73    23    23    0.154347      3.55         16.0
 052220   2281   05/19/73    17     1    0.040005      0.04        319.0
 052220   2282   05/21/73    15     1    0.010005      0.01         46.0
 052220   2283   05/21/73    19     1    0.040005      0.04          4.0
 052220   2284   05/21/73    24    11    0.032727      0.36         10.0
 052220   2285   05/24/73    12     1    0.010005      0.01         55.0
 052220   2286   05/24/73    19     4    0.025001      0.10          8.5
 052220   2287   05/26/73    15     1    0.010005      0.01         42.5
 052220   2288   05/29/73    22    14    0.059286      0.83         65.5
 052220   2289   06/01/73    15     1    0.010005      0.01         59.5
 052220   2290   06/03/73    16     5    0.016000      0.08         50.0
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052220    2291   06/04/73     9     2     0.040002     0.08      15.5
052220    2292   06/12/73    17     1     0.020005     0.02     199.5
052220    2293   06/14/73    12     1     0.010005     0.01      43.0
052220    2294   07/09/73    20     2     0.030002     0.06     608.5
052220    2295   07/12/73    19     4     0.067501     0.27      71.0
052220    2296   07/13/73    24     8     0.005000     0.04      32.0
052220    2297   07/15/73    15     5     0.006001     0.03      37.5
052220    2298   07/16/73    16     1     0.010005     0.01      23.0
052220    2299   07/18/73    21     1     0.020005     0.02      53.0
052220    2300   07/19/73     8     1     0.010005     0.01      11.0
052220    2301   07/19/73    12     4     0.005001     0.02       5.5
052220    2302   07/19/73    20     1     0.530004     0.53       6.5
052220    2303   07/20/73    15     1     0.010005     0.01      19.0
052220    2304   07/21/73     4     1     0.010005     0.01      13.0
052220    2305   07/21/73    13     2     0.045002     0.09       9.5
052220    2306   07/22/73    13     3     0.053334     0.19      24.5
052220    2307   07/23/73    24     1     0.020005     0.02      34.0
052220    2308   07/24/73    17     4     0.265001     1.06      19.5
052220    2309   07/30/73    15     5     0.016000     0.08     142.5
052220    2310   07/31/73    20     2     0.010002     0.02      27.5
052220    2311   08/05/73    16     1     0.020005     0.02     115.5
052220    2312   08/06/73    19     1     0.040005     0.04      26.0
052220    2313   08/07/73    15     2     0.475002     0.95      22.5
052220    2314   08/11/73    14     1     0.010005     0.01      93.5
052220    2315   08/21/73    17     1     0.050005     0.05     243.0
052220    2316   08/24/73    13     1     0.110004     0.11      68.0
052220    2317   08/28/73    15     1     0.010005     0.01      98.0
052220    2318   08/31/73     7     3     0.030001     0.09      65.0
052220    2319   09/02/73    18     1     0.030005     0.03      58.0
052220    2320   09/08/73    21     1     0.070004     0.07     147.0
052220    2321   09/09/73     2     4     0.030001     0.12       6.5
052220    2322   09/09/73    19     2     0.070002     0.14      16.0
052220    2323   09/10/73    15     1     0.020005     0.02      19.5
052220    2324   09/11/73     5     2     0.270002     0.54      14.5
052220    2325   09/11/73    14     1     0.110004     0.11       8.5
052220    2326   09/11/73    24     1     0.010005     0.01      10.0
052220    2327   09/15/73     9     1     0.010005     0.01      81.0
052220    2328   09/15/73    16     1     0.010005     0.01       7.0
052220    2329   09/16/73     5     1     0.010005     0.01      13.0
052220    2330   09/16/73    12     1     0.030005     0.03       7.0
052220    2331   09/16/73    20     1     0.010005     0.01       8.0
052220    2332   09/25/73    22     6     0.020000     0.12     220.5
052220    2333   09/27/73    24    33     0.049091     1.62      63.5
052220    2334   10/03/73     9     1     0.020005     0.02     113.0
052220    2335   10/03/73    17     2     0.010002     0.02       9.5
052220    2336   10/09/73    13     2     0.015002     0.03     140.0
052220    2337   10/09/73    21     1     0.010005     0.01       7.5
052220    2338   10/10/73     3     1     0.010005     0.01       6.0
052220    2339   10/10/73    16     3     0.010001     0.03      14.0
052220    2340   10/10/73    24     9     0.026667     0.24      11.0
052220    2341   10/29/73    22     4     0.027501     0.11     451.5
052220    2342   11/01/73    22     9     0.023333     0.21      74.5
052220    2343   11/02/73    23     1     0.010005     0.01      21.0
052220    2344   11/03/73    23    10     0.011000     0.11      28.5
052220    2345   11/19/73    14    11     0.035454     0.39     3 5.5
052220    2346   11/26/73    19     4     0.025001     0.10     169.5
052220    2347   11/27/73     2     1     0.010005     0.01       5.5
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052220    2348  12/02/73    19    10     0.071000       0.71       141.5
052220    2349  12/18/73     7    18     0.033333       0.60       376.0
052220    2350  12/23/73    13    16     0.076666       1.38       126.0
052220    2351  12/25/73    24     5     0.012001       0.06        52.5
052220    2352  12/29/73    21     3     0.010001       0.03        92.0
052220    2353  12/30/73    13     2     0.015002       0.03        15.5
052220    2354  12/30/73    18     5     0.006001       0.03         6.5


                                      NUMBER OF HOURS OF RAINFALL IN HUNDREDTHS OF AN INCH
                                            INTERVALS BETWEEN 0.00 AND 0.20 INCHES
MONTH    0     1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20     TOTAL
                                                                                                                                   &>     HOURS
                                                                                                                                            PER
                                                                                                                                          MONTH
   1   701    20     3     3     8     1     2     3     1     2     0     0     0     0     0     0     0     0     0     0     0       744
   2   665     4     1     0     1     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0       672
   3   683    28    10     7     6     2     1     3     2     0     1     0     0     0     0     0     0     0     0     0     1       744
   4   613    35    24    10    13     6     4     2     5     2     2     1     0     0     0     1     1     0     0     0     1       720
   5   679    16     6     4     9     2     5     3     1     0     1     0     2     1     3     0     4     0     0     0     8       744
   6   710     5     2     2     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       720
   7   709    19     3     3     0     1     3     1     0     0     0     0     0     2     0     0     0     0     0     0     3       744
   8   733     4     1     1     1     2     0     0     0     0     0     1     0     0     0     0     0     0     0     0     1       744
   9   664    14     9     7     8     3     3     3     2     0     0     1     1     1     1     2     0     0     0     0     1       720
  10   723    10     6     1     1     0     3     0     0     0     0     0     0     0     0     0     0     0     0     0     0       744
  11   687     8    13     7     2     1     1     0     0     1     0     0     0     0     0     0     0     0     0     0     0       720
  12   686    14    12     3     8     5     1     3     4     0     2     0     0     0     0     1     2     2     0     0     1       744
      8253   177    90    48    57    24    24    18    15     5     6     3     3     4     4     4     7     2     0     0    16

TOTAL HOURS FOR THE YEAR =   8760
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                                     RAINFALL STATISTICS BY  MONTH(FOR PERIOD OF RECORD)
MONTH               NUMBER        TOTAL        MINIMUM        MAXIMUM        AVERAGE        STD DEV        VARIANCE       COEF-VAR
    1
       DURATION     150.    0.764000E 03  0.100000E 01  0.490000E 02  0.509333E 01  0.656750E 01  0.431321E 02  0.128943E 01
       INTENSITY    150.    0.219561E 01  0.400000E-02  0.600010E-01  0.146440E-01  0.993968E-02  0.987973E-04  0.678751E 00
       VOLUME       150.    0.139794E 02  0.100000E-01  0.104000E 01  0.931992E-01  0.162456E 00  0.263922E-01  0.174311E 01
       DELTA        150.    0.186345E 05  0.400000E 01  0.107150E 04  0.124230E 03  0.166778E 03  0.278151E 05  0.134250E 01
    2
       DURATION     142.    0.841000E 03  0.100000E 01  0.330000E 02  0.592253E 01  0.632463E 01  0.400010E 02  0.106789E 01
       INTENSITY    142.    0.253509E 01  0.500000E-02  0.750010E-01  0.178597E-01  0.126667E-01  0.160447E-03  0.709236E 00
       VOLUME       142.    0.178898E 02  0.100000E-01  0.110000E 01  0.125985E 00  0.181689E 00  0.330111E-01  0.144215E 01
       DELTA        142.    0.179610E 05  0.500000E 01  0.787000E 03  0.126485E 03  0.144351E 03  0.208374E 05  0.114124E 01
    3
       DURATION     224.    0.129700E 04  0.100000E 01  0.370000E 02  0.579017E 01  0.653762E 01  0.427405E 02  0.112908E 01
       INTENSITY    224.    0.440279E 01  0.473700E-02  0.167501E 00  0.196553E-01  0.176819E-01  0.312651E-03  0.899599E 00
       VOLUME       224.    0.304396E 02  0.100000E-01  0.170000E 01  0.135891E 00  0.223920E 00  0.501404E-01  0.164779E 01
       DELTA        224.    0.184405E 05  0.400000E 01  0.860500E 03  0.823236E 02  0.106620E 03  0.113678E 05  0.129513E 01
    4
       DURATION     224.    0.131600E 04  0.100000E 01  0.420000E 02  0.587500E 01  0.723299E 01  0.523161E 02  0.123114E 01
       INTENSITY    224.    0.603282E 01  0.600100E-02  0.240004E 00  0.269322E-01  0.317325E-01  0.100695E-02  0.117823E 01
       VOLUME       224.    0.461494E 02  0.100000E-01  0.325000E 01  0.206024E 00  0.423935E 00  0.179536E 00  0.205720E 01
       DELTA        224.    0.185980E 05  0.400000E 01  0.821500E 03  0.829821E 02  0.109177E 03  0.119196E 05  0.131567E 01
    5
       DURATION     272.    0.138900E 04  0.100000E 01  0.590000E 02  0.510661E 01  0.760314E 01  0.578077E 02  0.148858E 01
       INTENSITY    272.    0.104375E 02  0.500100E-02  0.503334E 00  0.383731E-01  0.467756E-01  0.218924E-02  0.121904E 01
       VOLUME       272.    0.660992E 02  0.100000E-01  0.433000E 01  0.243011E 00  0.528912E 00  0.279748E 00  0.217648E 01
       DELTA        272.    0.194690E 05  0.400000E 01  0.636000E 03  0.715772E 02  0.947347E 02  0.897466E 04  0.132353E 01
    6
       DURATION     257.    0.769000E 03  0.100000E 01  0.350000E 02  0.299221E 01  0.397943E 01  0.158359E 02  0.132992E 01
       INTENSITY    257.    0.131649E 02  0.666800E-02  0.650001E 00  0.512256E-01  0.737433E-01  0.543807E-02  0.143957E 01
       VOLUME       257.    0.452395E 02  0.100000E-01  0.282000E 01  0.176029E 00  0.384295E 00  0.147683E 00  0.218313E 01
       DELTA        257.    0.171550E 05  0.400000E 01  0.366500E 03  0.667509E 02  0.739571E 02  0.546965E 04  0.110795E 01
    7
       DURATION     259.    0.675000E 03  0.100000E 01  0.220000E 02  0.260617E 01  0.264955E 01  0.701484E 01  0.101626E 01
       INTENSITY    259.    0.167371E 02  0.500000E-02  0.760004E 00  0.646221E-01  0.994411E-01  0.988853E-02  0.153880E 01
       VOLUME       259.    0.450894E 02  0.100000E-01  0.205000E 01  0.174090E 00  0.2970[illegible]E 00  0.882561E-01  0.170627E 01
       DELTA        259.    0.194705E 05  0.400000E 01  0.609500E 03  0.751756E 02  0.883221E 02  0.780079E 04  0.117487E 01
    8
       DURATION     233.    0.543000E 03  0.100000E 01  0.170000E 02  0.233047E 01  0.217900E 01  0.474807E 01  0.935006E 00
       INTENSITY    233.    0.135852E 02  0.500000E-02  0.675002E 00  0.583059E-01  0.944089E-01  0.891304E-02  0.161919E 01
       VOLUME       233.    0.340996E 02  0.100000E-01  0.343000E 01  0.146350E 00  0.309647E 00  0.958815E-01  0.211579E 01
       DELTA        233.    0.189285E 05  0.000000E 00  0.493000E 03  0.812382E 02  0.847613E 02  0.718449E 04  0.104336E 01
    9
       DURATION     171.    0.730000E 03  0.100000E 01  0.400000E 02  0.426900E 01  0.574129E 01  0.329624E 02  0.134487E 01
       INTENSITY    171.    0.830957E 01  0.500100E-02  0.655002E 00  0.485881E-01  0.732302E-01  0.536266E-02  0.150716E 01
       VOLUME       171.    0.351397E 02  0.100000E-01  0.164000E 01  0.205495E 00  0.334049E 00  0.111589E 00  0.162558E 01
       DELTA        171.    0.166235E 05  0.500000E 01  0.660500E 03  0.972134E 02  0.122170E 03  0.149257E 05  0.125672E 01
   10
       DURATION     132.    0.781000E 03  0.100000E 01  0.390000E 02  0.591666E 01  0.722278E 01  0.521685E 02  0.122075E 01
       INTENSITY    132.    0.368089E 01  0.600100E-02  0.170004E 00  0.278855E-01  0.281713E-01  0.793625E-03  0.101025E 01
       VOLUME       132.    0.253199E 02  0.100000E-01  0.170000E 01  0.191816E 00  0.306819E 00  0.941351E-01  0.159954E 01
       DELTA        132.    0.198020E 05  0.500000E 01  0.118150E 04  0.150010E 03  0.184240E 03  0.339446E 05  0.122814E 01
   11
       DURATION     139.    0.785000E 03  0.100000E 01  0.300000E 02  0.564748E 01  0.566308E 01  0.320704E 02  0.100276E 01
       INTENSITY    139.    0.281239E 01  0.500100E-02  0.775010E-01  0.202330E-01  0.145090E-01  0.210511E-03  0.717095E 00
       VOLUME       139.    0.187098E 02  0.100000E-01  0.820000E 00  0.134603E 00  0.174464E 00  0.304379E-01  0.129613E 01
       DELTA        139.    0.174025E 05  0.400000E 01  0.918000E 03  0.125197E 03  0.155972E 03  0.243273E 05  0.124580E 01
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12
  DURATION    151.  0.714000E 03  0.100000E 01  0.290000E 02  0.472847E 01  0.499324E 01  0.249324E 02  0.105599E 01
  INTENSITY   151.  0.249542E 01  0.500100E-02  0.766660E-01  0.165326E-01  0.115608E-01  0.133653E-03  0.699276E 00
  VOLUME      151.  0.147398E 02  0.100000E-01  0.138000E 01  0.976150E-01  0.166791E 00  0.278195E-01  0.170866E 01
  DELTA       151.  0.202905E 05  0.400000E 01  0.763000E 03  0.134374E 03  0.172661E 03  0.298119E 05  0.128493E 01
```

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                SUMMARY OF RAINFALL STATISTICS BY  MONTH(FOR PERIOD OF RECORD)
MONTH      DURATION                 INTENSITY              VOLUME               DELTA
        AVERAGE   STD DEV      AVERAGE   STD DEV      AVERAGE   STD DEV    AVERAGE   STD DEV
  1.      5.09       6.56      0.0146    0.0099        0.09      0.16       124.      166.
  2.      5.92       6.32      0.0176    0.0126        0.12      0.18       126.      144.
  3.      5.79       6.53      0.0196    0.0176        0.13      0.22        82.      106.
  4.      5.87       7.28      0.0269    0.0317        0.20      0.42        82.      109.
  5.      5.10       7.60      0.0383    0.0467        0.24      0.52        71.       94.
  6.      2.99       3.97      0.0512    0.0737        0.17      0.38        66.       73.
  7.      2.60       2.64      0.0646    0.0994        0.17      0.29        75.       88.
  8.      2.33       2.17      0.0583    0.0944        0.14      0.30        81.       84.
  9.      4.26       5.74      0.0485    0.0732        0.20      0.33        97.      122.
 10.      5.91       7.22      0.0278    0.0281        0.19      0.30       150.      184.
 11.      5.64       5.66      0.0202    0.0145        0.13      0.17       125.      155.
 12.      4.72       4.99      0.0165    0.0115        0.09      0.16       134.      172.
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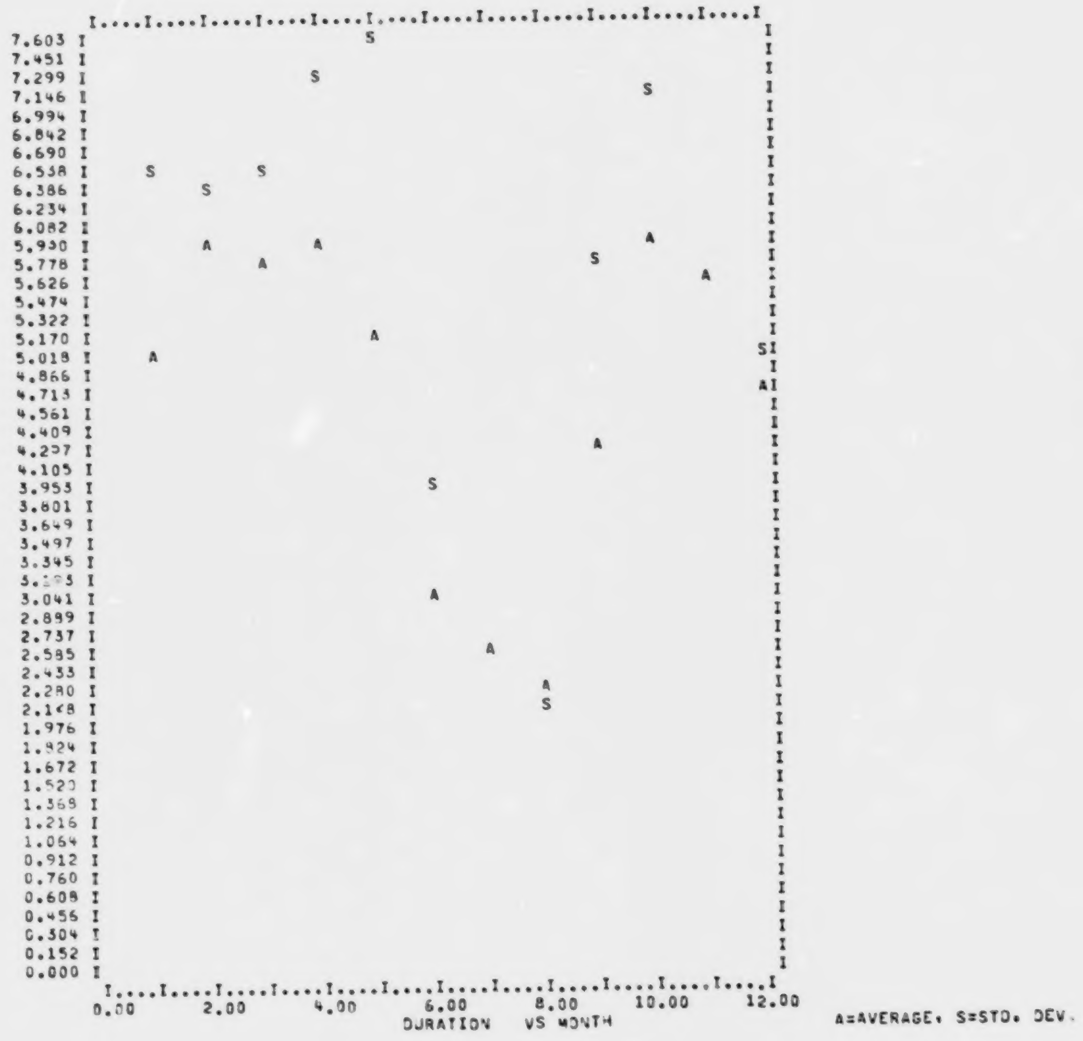
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4.866
4.713
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4.257
4.105
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1.824
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1.064
0.912
0.760
0.608
0.456
0.304
0.152
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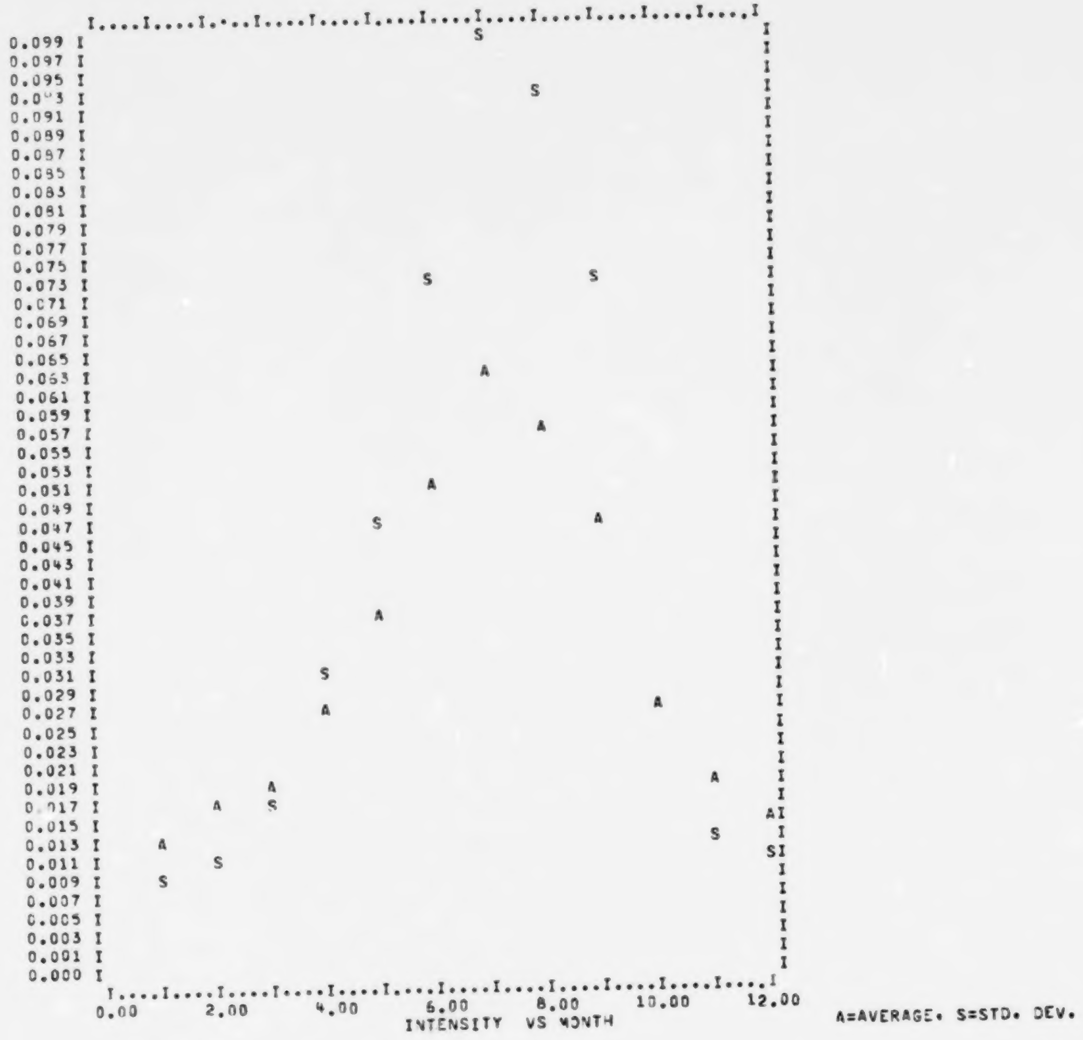
4.00
6.00
8.00
10.00
12.00
DURATION VS MONTH
A=AVERAGE, S=STD. DEV.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0.071
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0.067
0.065
0.063
0.061
0.059
0.057
0.055
0.053
0.051
0.049
0.047
0.045
0.043
0.041
0.039
0.037
0.035
0.033
0.031
0.029
0.027
0.025
0.023
0.021
0.019
0.017
0.015
0.013
0.011
0.009
0.007
0.005
0.003
0.001
0.000
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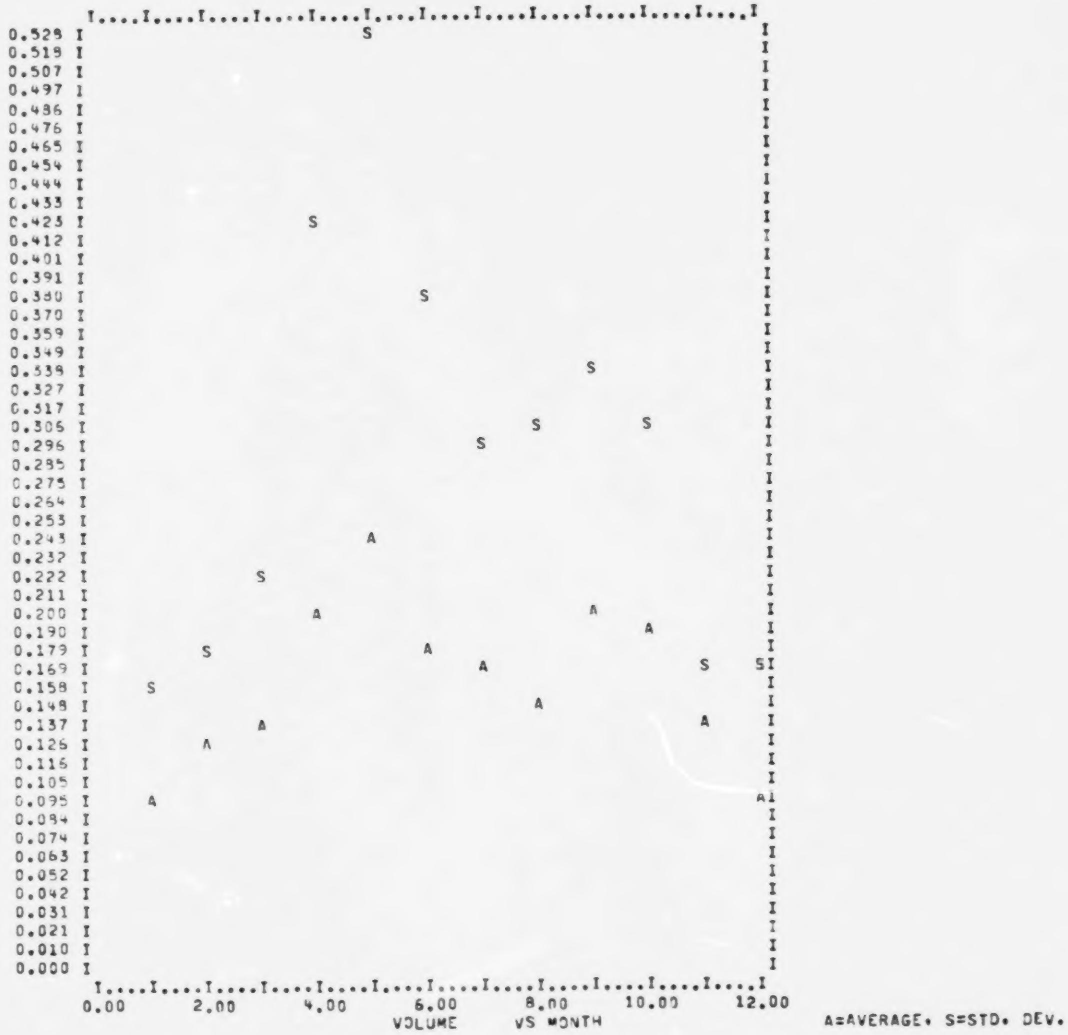
4.00
6.00
8.00
10.00
12.00
INTENSITY VS MONTH
A=AVERAGE. S=STD. DEV.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0.401
0.391
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0.370
0.359
0.349
0.339
0.327
0.317
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0.296
0.285
0.275
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0.253
0.243
0.232
0.222
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0.200
0.190
0.179
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0.158
0.148
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0.042
0.031
0.021
0.010
0.000
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4.00
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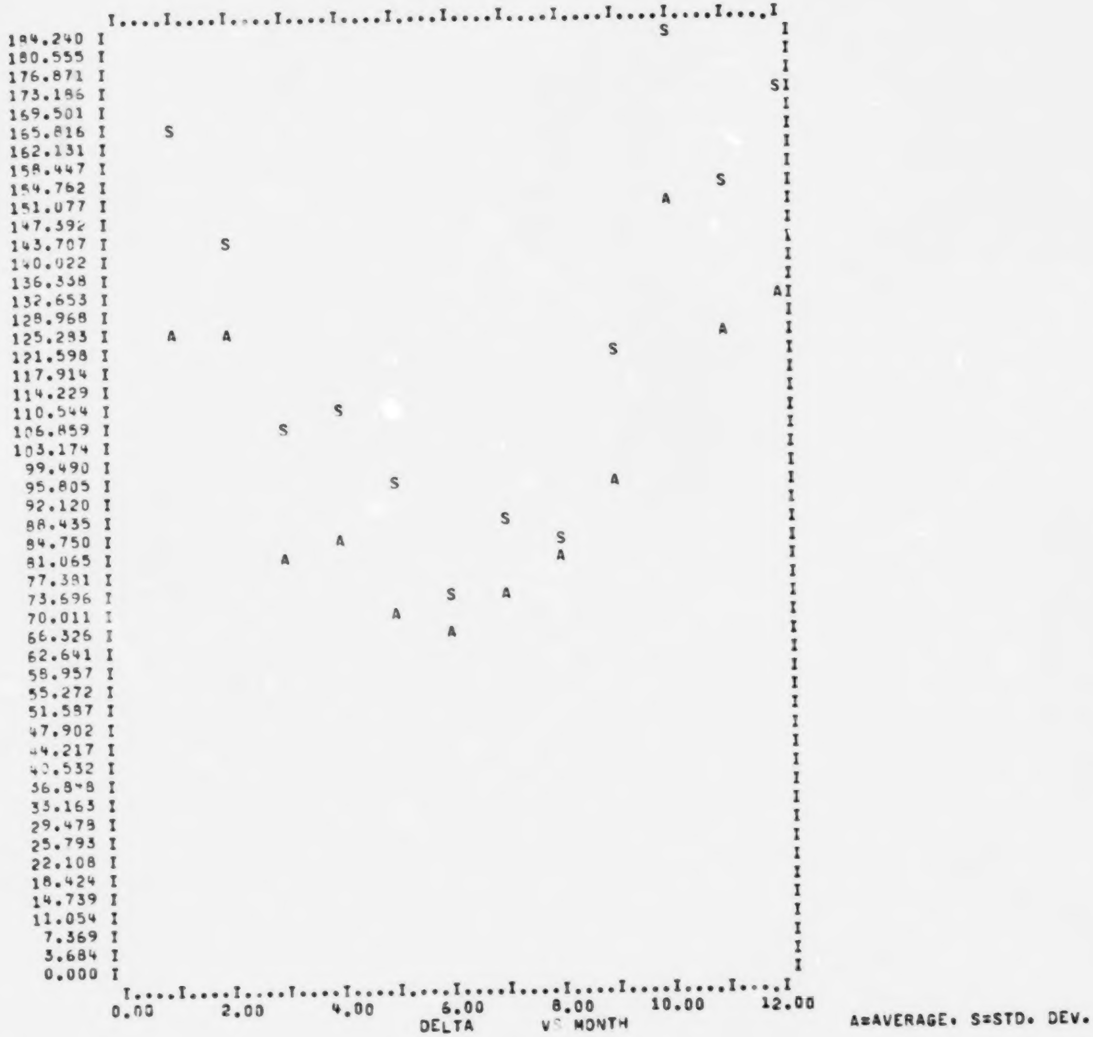
VOLUME VS MONTH
A=AVERAGE, S=STD. DEV.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7.369
3.684
0.000
0.00
2.00
4.00
6.00
8.00
10.00
12.00
DELTA VS MONTH
A=AVERAGE. S=STD. DEV.

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                                    RAINFALL STATISTICS BY   YEAR(FOR PERIOD OF RECORD)
YEAR              NUMBER        TOTAL        MINIMUM        MAXIMUM        AVERAGE        STD DEV       VARIANCE       COEF-VAR
 48
     DURATION       24.  0.100000E 03  0.100000E 01  0.230000E 02  0.416666E 01  0.532154E 01  0.283198E 02  0.127717E 01
     INTENSITY      24.  0.724532E 00  0.666800E-02  0.133334E 00  0.301930E-01  0.393428E-01  0.154786E-02  0.130304E 01
     VOLUME         24.  0.192999E 01  0.100000E-01  0.400000E 00  0.804166E-01  0.947067E-01  0.896937E-02  0.117770E 01
     DELTA          24.  0.355350E 04  0.000000E 00  0.763000E 03  0.148062E 03  0.191573E 03  0.367002E 05  0.129386E 01
 49
     DURATION      111.  0.536000E 03  0.100000E 01  0.490000E 02  0.482882E 01  0.780661E 01  0.609431E 02  0.161656E 01
     INTENSITY     111.  0.336794E 01  0.636400E-02  0.200004E 00  0.303418E-01  0.339153E-01  0.115025E-02  0.111777E 01
     VOLUME        111.  0.167799E 02  0.100000E-01  0.196000E 01  0.151170E 00  0.289182E 00  0.836263E-01  0.191295E 01
     DELTA         111.  0.857700E 04  0.400000E 01  0.717000E 03  0.772702E 02  0.112657E 03  0.126917E 05  0.145797E 01
 50
     DURATION       62.  0.332000E 03  0.100000E 01  0.290000E 02  0.535483E 01  0.622290E 01  0.387244E 02  0.116210E 01
     INTENSITY      62.  0.265045E 01  0.400000E-02  0.412000E 00  0.427493E-01  0.667652E-01  0.445799E-02  0.156185E 01
     VOLUME         62.  0.139399E 02  0.100000E-01  0.213000E 01  0.224838E 00  0.424803E 00  0.180457E 00  0.188937E 01
     DELTA          62.  0.903950E 04  0.700000E 01  0.759500E 03  0.145798E 03  0.156591E 03  0.245209E 05  0.107402E 01
 51
     DURATION      110.  0.499000E 03  0.100000E 01  0.250000E 02  0.453636E 01  0.511640E 01  0.261775E 02  0.112786E 01
     INTENSITY     110.  0.429033E 01  0.571400E-02  0.650004E 00  0.390030E-01  0.798531E-01  0.637652E-02  0.204735E 01
     VOLUME        110.  0.194199E 02  0.100000E-01  0.343000E 01  0.176544E 00  0.394613E 00  0.155719E 00  0.223520E 01
     DELTA         110.  0.874300E 04  0.450000E 01  0.459500E 03  0.794818E 02  0.920243E 02  0.846948E 04  0.115780E 01
 52
     DURATION       85.  0.415000E 03  0.100000E 01  0.370000E 02  0.488235E 01  0.700410E 01  0.490574E 02  0.143457E 01
     INTENSITY      85.  0.239083E 01  0.583300E-02  0.260004E 00  0.281274E-01  0.328243E-01  0.107743E-02  0.116698E 01
     VOLUME         85.  0.135599E 02  0.100000E-01  0.150000E 01  0.159528E 00  0.305558E 00  0.933658E-01  0.191538E 01
     DELTA          85.  0.880500E 04  0.500000E 01  0.787000E 03  0.103588E 03  0.125816E 03  0.158296E 05  0.121458E 01
 53
     DURATION       86.  0.409000E 03  0.100000E 01  0.330000E 02  0.475581E 01  0.603701E 01  0.364455E 02  0.126939E 01
     INTENSITY      86.  0.270241E 01  0.500100E-02  0.350001E 00  0.314233E-01  0.450213E-01  0.202692E-02  0.143273E 01
     VOLUME         86.  0.141099E 02  0.100000E-01  0.187000E 01  0.164069E 00  0.290116E 00  0.841675E-01  0.176825E 01
     DELTA          86.  0.864450E 04  0.500000E 01  0.606000E 03  0.100517E 03  0.124448E 03  0.154573E 05  0.123807E 01
 54
     DURATION       68.  0.236000E 03  0.100000E 01  0.210000E 02  0.347058E 01  0.415545E 01  0.172677E 02  0.119733E 01
     INTENSITY      68.  0.240782E 01  0.666700E-02  0.420004E 00  0.354091E-01  0.601270E-01  0.361526E-02  0.169806E 01
     VOLUME         68.  0.750998E 01  0.100000E-01  0.115000E 01  0.110440E 00  0.191158E 00  0.365414E-01  0.173086E 01
     DELTA          68.  0.875200E 04  0.450000E 01  0.757000E 03  0.128705E 03  0.147062E 03  0.216273E 05  0.114262E 01
 55
     DURATION       82.  0.352000E 03  0.100000E 01  0.330000E 02  0.429268E 01  0.573593E 01  0.329009E 02  0.133621E 01
     INTENSITY      82.  0.407680E 01  0.666800E-02  0.655002E 00  0.497171E-01  0.846472E-01  0.716516E-02  0.170257E 01
     VOLUME         82.  0.160499E 02  0.100000E-01  0.137000E 01  0.195731E 00  0.322757E 00  0.104172E 00  0.164896E 01
     DELTA          82.  0.818550E 04  0.400000E 01  0.649000E 03  0.998231E 02  0.128251E 03  0.164484E 05  0.128478E 01
 56
     DURATION       70.  0.356000E 03  0.100000E 01  0.300000E 02  0.508571E 01  0.559954E 01  0.313548E 02  0.110103E 01
     INTENSITY      70.  0.305555E 01  0.666800E-02  0.675002E 00  0.436507E-01  0.864786E-01  0.746991E-02  0.198000E 01
     VOLUME         70.  0.137199E 02  0.100000E-01  0.161000E 01  0.195999E 00  0.322316E 00  0.103887E 00  0.164447E 01
     DELTA          70.  0.924550E 04  0.650000E 01  0.118150E 04  0.132078E 03  0.202405E 03  0.409680E 05  0.153246E 01
 57
     DURATION      111.  0.456000E 03  0.100000E 01  0.320000E 02  0.410810E 01  0.542276E 01  0.294063E 02  0.132001E 01
     INTENSITY     111.  0.430027E 01  0.500000E-02  0.240004E 00  0.387412E-01  0.466055E-01  0.217207E-02  0.120299E 01
     VOLUME        111.  0.215798E 02  0.100000E-01  0.329000E 01  0.194413E 00  0.449628E 00  0.202165E 00  0.231274E 01
     DELTA         111.  0.840450E 04  0.450000E 01  0.422000E 03  0.757162E 02  0.967613E 02  0.936276E 04  0.127794E 01
 58
     DURATION      103.  0.497000E 03  0.100000E 01  0.230000E 02  0.482524E 01  0.495554E 01  0.245573E 02  0.102700E 01
     INTENSITY     103.  0.514908E 01  0.500100E-02  0.520004E 00  0.499910E-01  0.880508E-01  0.775294E-02  0.176133E 01
     VOLUME        103.  0.187999E 02  0.100000E-01  0.151000E 01  0.182523E 00  0.262636E 00  0.689776E-01  0.143891E 01
     DELTA         103.  0.932500E 04  0.400000E 01  0.902000E 03  0.905339E 02  0.133838E 03  0.179127E 05  0.147832E 01
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59
  DURATION      88.  0.504000E 03  0.100000E 01  0.420000E 02  0.572727E 01  0.745673E 01  0.556029E 02  0.130197E 01
  INTENSITY     88.  0.252017E 01  0.500100E-02  0.190004E 00  0.236383E-01  0.275740E-01  0.760328E-03  0.962836E 00
  VOLUME        88.  0.165399E 02  0.100000E-01  0.170000E 01  0.167953E 00  0.315179E 00  0.993378E-01  0.167689E 01
  DELTA         88.  0.864950E 04  0.400000E 01  0.660500E 03  0.982897E 02  0.117992E 03  0.139221E 05  0.120045E 01
60
  DURATION      74.  0.442000E 03  0.100000E 01  0.290000E 02  0.597297E 01  0.733722E 01  0.538348E 02  0.122840E 01
  INTENSITY     74.  0.253318E 01  0.571400E-02  0.320002E 00  0.342322E-01  0.472798E-01  0.223538E-02  0.138115E 01
  VOLUME        74.  0.149799E 02  0.100000E-01  0.157000E 01  0.202431E 00  0.301883E 00  0.911336E-01  0.149128E 01
  DELTA         74.  0.881700E 04  0.550000E 01  0.510500E 03  0.119148E 03  0.134031E 03  0.179645E 05  0.112491E 01
61
  DURATION     111.  0.519000E 03  0.100000E 01  0.330000E 02  0.467567E 01  0.584677E 01  0.341847E 02  0.125046E 01
  INTENSITY    111.  0.350318E 01  0.500100E-02  0.345002E 00  0.315602E-01  0.446170E-01  0.199067E-02  0.141370E 01
  VOLUME       111.  0.190098E 02  0.100000E-01  0.215000E 01  0.171260E 00  0.321136E 00  0.103128E 00  0.187513E 01
  DELTA        111.  0.872950E 04  0.400000E 01  0.523000E 03  0.786351E 02  0.100344E 03  0.100689E 05  0.127607E 01
62
  DURATION      87.  0.319000E 03  0.100000E 01  0.270000E 02  0.366666E 01  0.439255E 01  0.192945E 02  0.119797E 01
  INTENSITY     87.  0.188387E 01  0.500000E-02  0.120002E 00  0.217112E-01  0.200854E-01  0.403426E-03  0.925118E 00
  VOLUME        87.  0.844395E 01  0.100000E-01  0.104000E 01  0.971259E-01  0.172099E 00  0.296182E-01  0.177192E 01
  DELTA         67.  0.872050E 04  0.500000E 01  0.741000E 03  0.100235E 03  0.133498E 03  0.178219E 05  0.133184E 01
63
  DURATION      87.  0.362000E 03  0.100000E 01  0.290000E 02  0.416092E 01  0.549814E 01  0.302296E 02  0.132137E 01
  INTENSITY     87.  0.332089E 01  0.500100E-02  0.420004E 00  0.381711E-01  0.592150E-01  0.350642E-02  0.155130E 01
  VOLUME        87.  0.122299E 02  0.100000E-01  0.222000E 01  0.140574E 00  0.277338E 00  0.769168E-01  0.197290E 01
  DELTA         87.  0.887000E 04  0.450000E 01  0.821500E 03  0.101954E 03  0.145820E 03  0.212636E 05  0.143025E 01
64
  DURATION      84.  0.355000E 03  0.100000E 01  0.290000E 02  0.422619E 01  0.555661E 01  0.308759E 02  0.131480E 01
  INTENSITY     84.  0.223807E 01  0.500100E-02  0.130005E 00  0.266437E-01  0.259012E-01  0.670872E-03  0.972131E 00
  VOLUME        84.  0.101399E 02  0.100000E-01  0.176000E 01  0.120713E 00  0.234313E 00  0.549028E-01  0.194106E 01
  DELTA         84.  0.876250E 04  0.500000E 01  0.556000E 03  0.104196E 03  0.114026E 03  0.130019E 05  0.109433E 01
65
  DURATION     114.  0.532000E 03  0.100000E 01  0.370000E 02  0.466666E 01  0.569997E 01  0.324896E 02  0.122142E 01
  INTENSITY    114.  0.442006E 01  0.500100E-02  0.341667E 00  0.387725E-01  0.504913E-01  0.254937E-02  0.130224E 01
  VOLUME       114.  0.218698E 02  0.100000E-01  0.277000E 01  0.191841E 00  0.366855E 00  0.134582E 00  0.191228E 01
  DELTA        114.  0.865150E 04  0.500000E 01  0.918000E 03  0.758903E 02  0.121041E 03  0.146511E 05  0.159495E 01
66
  DURATION      91.  0.289000E 03  0.100000E 01  0.160000E 02  0.317582E 01  0.333964E 01  0.111465E 02  0.105126E 01
  INTENSITY     91.  0.408537E 01  0.500000E-02  0.640004E 00  0.448941E-01  0.826990E-01  0.683912E-02  0.184208E 01
  VOLUME        91.  0.108099E 02  0.100000E-01  0.800000E 00  0.118790E 00  0.168383E 00  0.283529E-01  0.141747E 01
  DELTA         91.  0.886200E 04  0.400000E 01  0.660500E 03  0.973846E 02  0.133247E 03  0.177549E 05  0.136826E 01
67
  DURATION     124.  0.477000E 03  0.100000E 01  0.260000E 02  0.384677E 01  0.455150E 01  0.207161E 02  0.118319E 01
  INTENSITY    124.  0.622948E 01  0.600100E-02  0.650001E 00  0.502293E-01  0.830309E-01  0.689413E-02  0.165303E 01
  VOLUME       124.  0.233098E 02  0.100000E-01  0.325000E 01  0.187982E 00  0.391811E 00  0.153515E 00  0.208429E 01
  DELTA        124.  0.882900E 04  0.400000E 01  0.550000E 03  0.712016E 02  0.941286E 02  0.886020E 04  0.132200E 01
68
  DURATION      89.  0.368000E 03  0.100000E 01  0.270000E 02  0.407865E 01  0.468126E 01  0.219141E 02  0.114774E 01
  INTENSITY     89.  0.324160E 01  0.500100E-02  0.390002E 00  0.364224E-01  0.517360E-01  0.267662E-02  0.142044E 01
  VOLUME        89.  0.121299E 02  0.100000E-01  0.143000E 01  0.136291E 00  0.213383E 00  0.455324E-01  0.156564E 01
  DELTA         89.  0.878550E 04  0.400000E 01  0.405000E 03  0.987134E 02  0.106823E 03  0.114112E 05  0.108215E 01
69
  DURATION     105.  0.497000E 03  0.100000E 01  0.580000E 02  0.473333E 01  0.819036E 01  0.670820E 02  0.173035E 01
  INTENSITY    105.  0.389584E 01  0.500100E-02  0.416668E 00  0.371128E-01  0.616595E-01  0.380189E-02  0.166140E 01
  VOLUME       105.  0.215098E 02  0.100000E-01  0.433000E 01  0.204855E 00  0.510391E 00  0.260499E 00  0.249146E 01
  DELTA        105.  0.874700E 04  0.400000E 01  0.420000E 03  0.833047E 02  0.930079E 02  0.865047E 04  0.111647E 01
70
  DURATION      86.  0.374000E 03  0.100000E 01  0.220000E 02  0.434883E 01  0.471235E 01  0.222062E 02  0.108358E 01
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    INTENSITY     86.  0.265086E 01  0.473700E-02  0.190001E 00  0.308239E-01  0.339786E-01  0.115455E-02  0.110234E 01
    VOLUME        86.  0.137299E 02  0.100000E-01  0.282000E 01  0.159650E 00  0.362936E 00  0.131722E 00  0.227331E 01
    DELTA         86.  0.828500E 04  0.400000E 01  0.860500E 03  0.953372E 02  0.130546E 03  0.170424E 05  0.135510E 01
71
    DURATION      78.  0.398000E 03  0.100000E 01  0.400000E 02  0.510256E 01  0.687663E 01  0.472880E 02  0.134768E 01
    INTENSITY     78.  0.264446E 01  0.600000E-02  0.760004E 00  0.339033E-01  0.905136E-01  0.819272E-02  0.266975E 01
    VOLUME        79.  0.109599E 02  0.100000E-01  0.160000E 01  0.140512E 00  0.268893E 00  0.723034E-01  0.191366E 01
    DELTA         78.  0.915750E 04  0.400000E 01  0.540000E 03  0.117403E 03  0.139766E 03  0.195346E 05  0.119047E 01
72
    DURATION     107.  0.431000E 03  0.100000E 01  0.240000E 02  0.402803E 01  0.504406E 01  0.254425E 02  0.125223E 01
    INTENSITY    107.  0.373026E 01  0.500100E-02  0.302501E 00  0.348622E-01  0.487233E-01  0.237595E-02  0.139759E 01
    VOLUME       107.  0.168699E 02  0.100000E-01  0.304000E 01  0.157662E 00  0.359712E 00  0.129392E 00  0.228153E 01
    DELTA        107.  0.885900E 04  0.400000E 01  0.554000E 03  0.827944E 02  0.103978E 03  0.108115E 05  0.125586E 01
73
    DURATION     117.  0.554000E 03  0.100000E 01  0.330000E 02  0.473504E 01  0.637667E 01  0.406619E 02  0.134669E 01
    INTENSITY    117.  0.437354E 01  0.500000E-02  0.530004E 00  0.373807E-01  0.732807E-01  0.537006E-02  0.196038E 01
    VOLUME       117.  0.229598E 02  0.100000E-01  0.355000E 01  0.196238E 00  0.434959E 00  0.189189E 00  0.221648E 01
    DELTA        117.  0.877600E 04  0.400000E 01  0.608500E 03  0.750085E 02  0.100784E 03  0.101574E 05  0.134363E 01
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           SUMMARY OF RAINFALL STATISTICS BY   YEAR(FOR PERIOD OF RECORD)
YEAR      DURATION            INTENSITY              VOLUME              DELTA
       AVERAGE   STD DEV   AVERAGE   STD DEV   AVERAGE   STD DEV   AVERAGE   STD DEV
 48.     4.16      5.32    0.0301    0.0393     0.08      0.09      148.      191.
 49.     4.92      7.80    0.0303    0.0339     0.15      0.28       77.      112.
 50.     5.35      6.22    0.0427    0.0667     0.22      0.42      145.      156.
 51.     4.53      5.11    0.0390    0.0798     0.17      0.39       79.       92.
 52.     4.89      7.00    0.0291    0.0328     0.15      0.30      103.      125.
 53.     4.75      6.03    0.0314    0.0450     0.16      0.29      100.      124.
 54.     3.47      4.15    0.0354    0.0601     0.11      0.19      128.      147.
 55.     4.29      5.73    0.0497    0.0846     0.19      0.32       99.      128.
 56.     5.08      5.59    0.0436    0.0864     0.19      0.32      132.      202.
 57.     4.10      5.42    0.0397    0.0466     0.19      0.44       75.       96.
 58.     4.92      4.95    0.0499    0.0980     0.18      0.26       90.      133.
 59.     5.72      7.45    0.0286    0.0275     0.18      0.31       98.      117.
 60.     5.97      7.33    0.0342    0.0472     0.20      0.30      119.      134.
 61.     4.67      5.84    0.0315    0.0446     0.17      0.32       78.      100.
 62.     3.66      4.39    0.0217    0.0200     0.09      0.17      100.      133.
 63.     4.16      5.49    0.0391    0.0592     0.14      0.27      101.      145.
 64.     4.22      5.55    0.0266    0.0259     0.12      0.23      104.      114.
 65.     4.66      5.69    0.0397    0.0504     0.19      0.36       75.      121.
 66.     3.17      3.33    0.0448    0.0826     0.11      0.16       97.      133.
 67.     3.94      4.55    0.0502    0.0830     0.18      0.39       71.       94.
 68.     4.07      4.69    0.0364    0.0517     0.13      0.21       98.      106.
 69.     4.73      8.19    0.0371    0.0616     0.20      0.51       83.       93.
 70.     4.34      4.71    0.0304    0.0339     0.15      0.36       96.      130.
 71.     5.10      6.87    0.0339    0.0905     0.14      0.26      117.      139.
 72.     4.02      5.04    0.0348    0.0487     0.15      0.35       82.      103.
 73.     4.73      6.37    0.0373    0.0732     0.19      0.43       75.      100.
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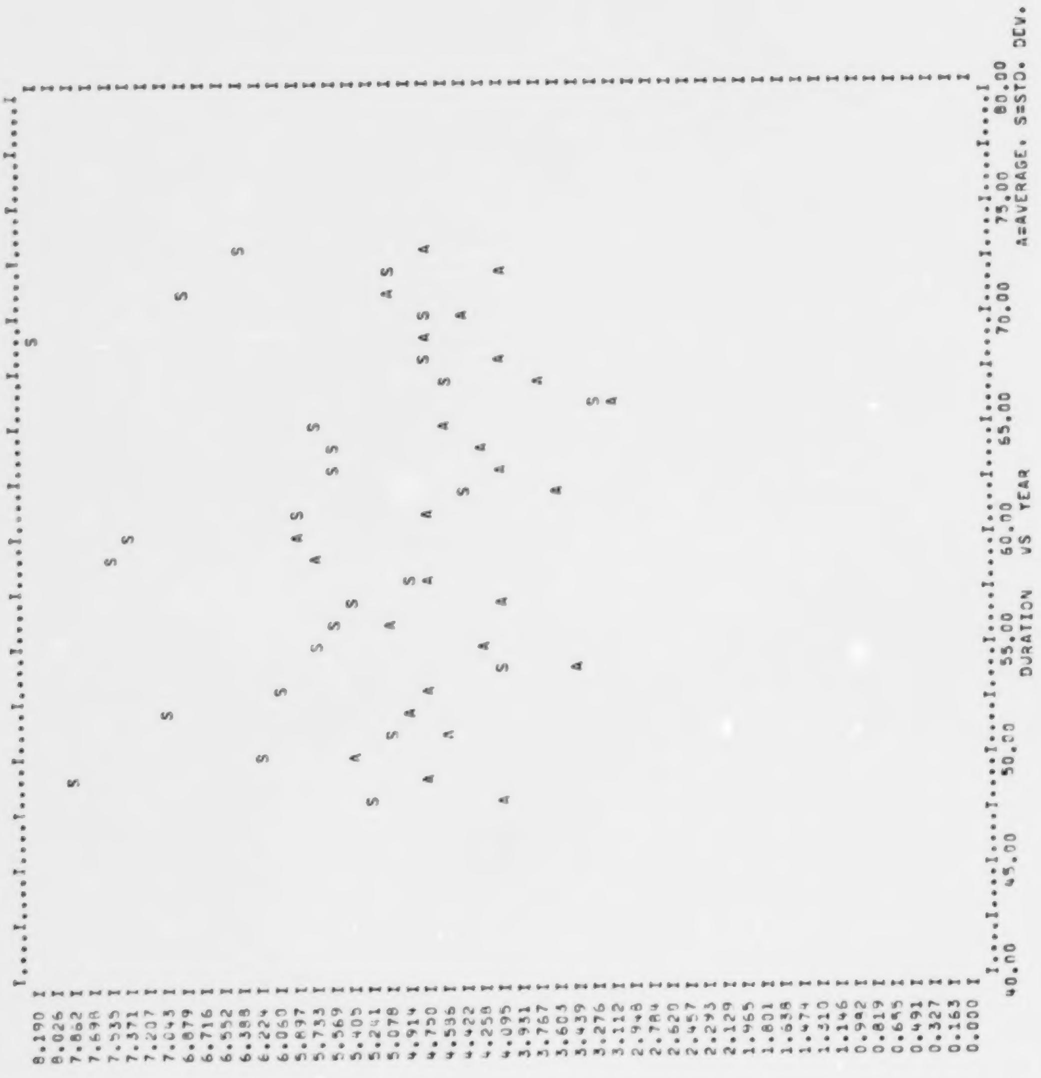
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75.00
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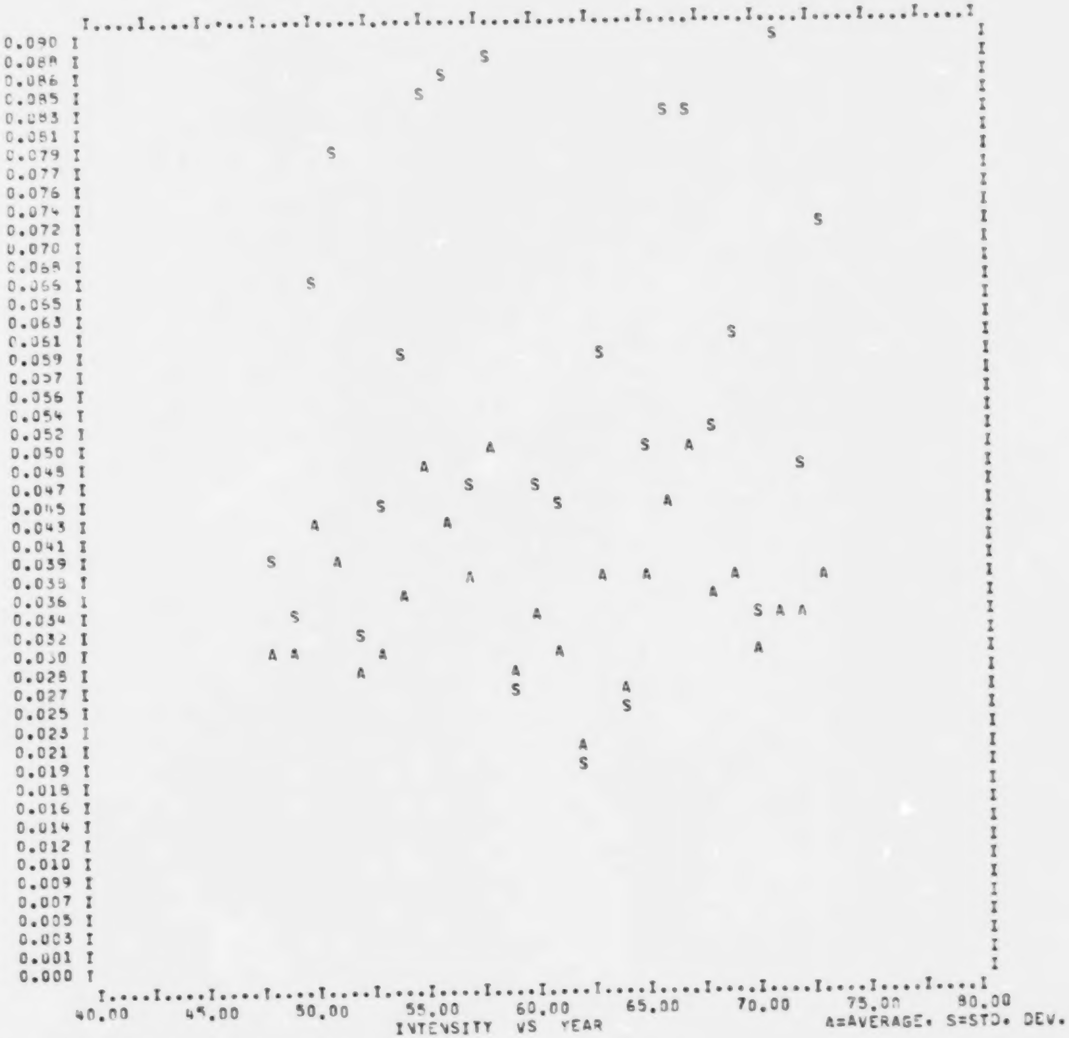
DURATION VS YEAR
A=AVERAGE, S=STD. DEV.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0.001
0.000
40.00
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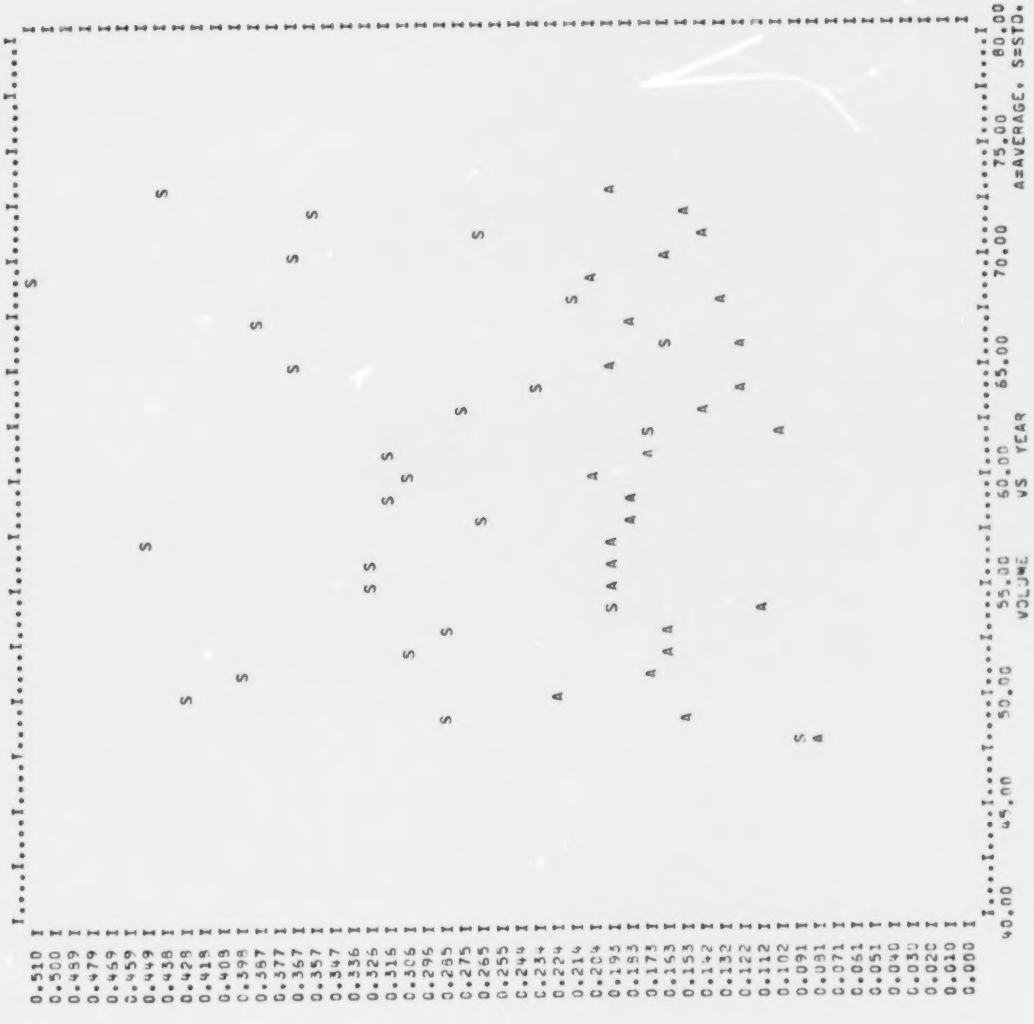
60.00
65.00
70.00
75.00
80.00
INTENSITY VS YEAR
A=AVERAGE, S=STD. DEV.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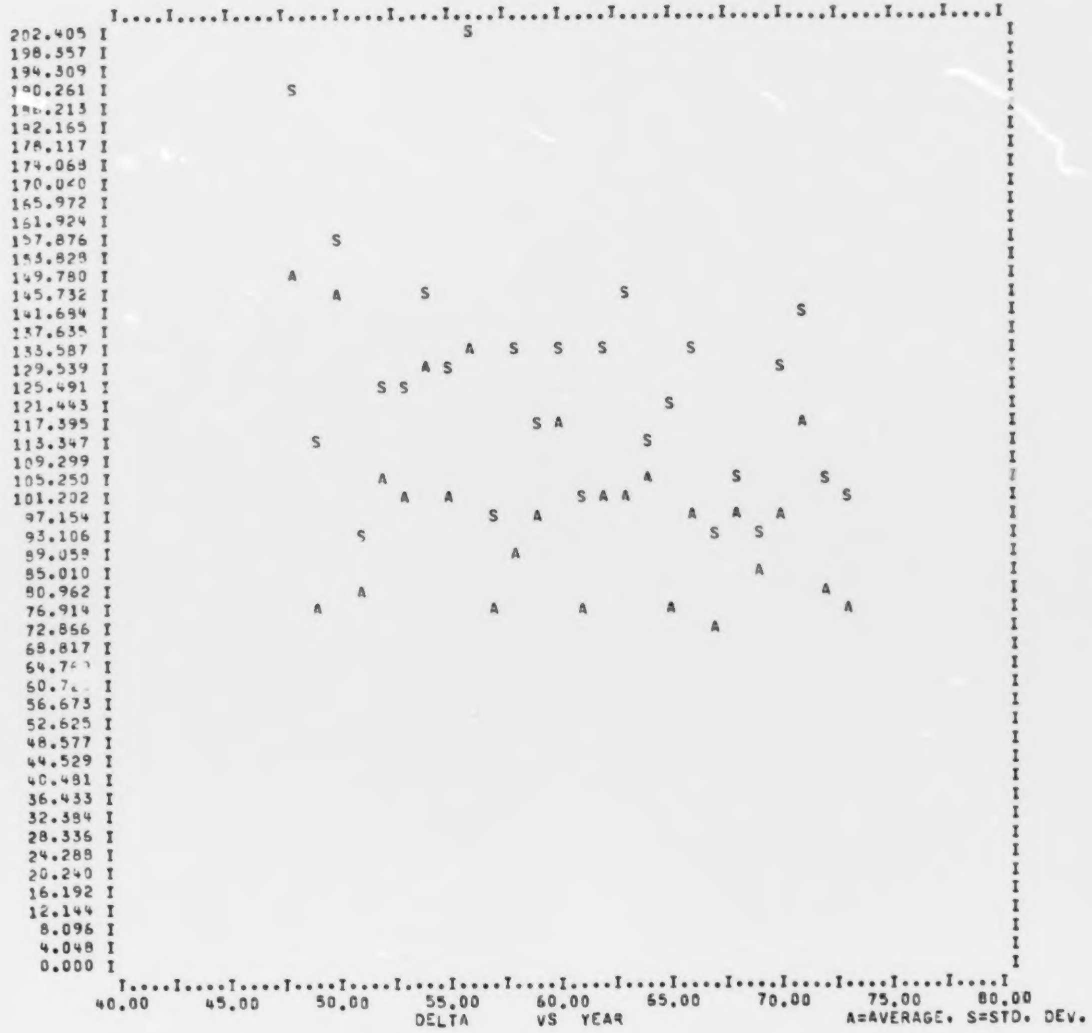
VOLUME VS YEAR
A=AVERAGE, S=STD. DEV.

202.405
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60.00
65.00
70.00
75.00
80.00
DELTA VS YEAR
A=AVERAGE, S=STD. DEV.

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                                 PROBABILITY ANALYSIS-DURATION

          PERCENTAGE OF OCCURRENCE LESS THAN OR EQUAL TO THE GIVEN VALUE OF DURATION

VALUE    PCT   VALUE    PCT   VALUE    PCT   VALUE    PCT   VALUE    PCT   VALUE    PCT   VALUE    PCT   VALUE    PCT
1.000   0.042  1.000   0.084  1.000   0.127  1.000   0.169  1.000   0.2[illegible]  1.000   0.254  1.000   0.297  1.000   0.339
1.000   0.382  1.000   0.424  1.000   0.467  1.000   0.509  1.000   0.5[illegible]  1.000   0.594  1.000   0.637  1.000   0.679
1.000   0.722  1.000   0.764  1.000   0.807  1.000   0.849  1.000   0.892  1.000   0.934  1.000   0.977  1.000   1.019
1.000   1.062  1.000   1.104  1.000   1.146  1.000   1.189  1.000   1.231  1.000   1.274  1.000   1.316  1.000   1.359
1.000   1.401  1.000   1.444  1.000   1.486  1.000   1.529  1.000   1.571  1.000   1.614  1.000   1.656  1.000   1.699
1.000   1.741  1.000   1.784  1.000   1.826  1.000   1.869  1.000   1.911  1.000   1.954  1.000   1.996  1.000   2.039
1.000   2.081  1.000   2.124  1.000   2.166  1.000   2.209  1.000   2.251  1.000   2.293  1.000   2.336  1.000   2.378
1.000   2.421  1.000   2.463  1.000   2.506  1.000   2.548  1.000   2.591  1.000   2.633  1.000   2.676  1.000   2.718
1.000   2.761  1.000   2.803  1.000   2.846  1.000   2.888  1.000   2.931  1.000   2.973  1.000   3.016  1.000   3.058
1.000   3.101  1.000   3.143  1.000   3.186  1.000   3.228  1.000   3.271  1.000   3.313  1.000   3.355  1.000   3.398
1.000   3.440  1.000   3.483  1.000   3.525  1.000   3.568  1.000   3.610  1.000   3.653  1.000   3.695  1.000   3.738
1.000   3.780  1.000   3.823  1.000   3.865  1.000   3.908  1.000   3.950  1.000   3.993  1.000   4.035  1.000   4.078
1.000   4.120  1.000   4.163  1.000   4.205  1.000   4.248  1.000   4.290  1.000   4.333  1.000   4.375  1.000   4.418
1.000   4.460  1.000   4.502  1.000   4.545  1.000   4.587  1.000   4.630  1.000   4.672  1.000   4.715  1.000   4.757
1.000   4.800  1.000   4.842  1.000   4.885  1.000   4.927  1.000   4.970  1.000   5.012  1.000   5.055  1.000   5.097
1.000   5.140  1.000   5.182  1.000   5.225  1.000   5.267  1.000   5.310  1.000   5.352  1.000   5.395  1.000   5.437
1.000   5.480  1.000   5.522  1.000   5.564  1.000   5.607  1.000   5.649  1.000   5.692  1.000   5.734  1.000   5.777
1.000   5.819  1.000   5.862  1.000   5.904  1.000   5.947  1.000   5.989  1.000   6.032  1.000   6.074  1.000   6.117
1.000   6.159  1.000   6.202  1.000   6.244  1.000   6.287  1.000   6.329  1.000   6.372  1.000   6.414  1.000   6.457
1.000   6.499  1.000   6.542  1.000   6.584  1.000   6.627  1.000   6.669  1.000   6.711  1.000   6.754  1.000   6.796
1.000   6.839  1.000   6.881  1.000   6.924  1.000   6.966  1.000   7.009  1.000   7.051  1.000   7.094  1.000   7.136
1.000   7.179  1.000   7.221  1.000   7.264  1.000   7.306  1.000   7.349  1.000   7.391  1.000   7.434  1.000   7.476
1.000   7.519  1.000   7.561  1.000   7.604  1.000   7.646  1.000   7.689  1.000   7.731  1.000   7.774  1.000   7.816
1.000   7.858  1.000   7.901  1.000   7.943  1.000   7.986  1.000   8.028  1.000   8.071  1.000   8.113  1.000   8.156
1.000   8.198  1.000   8.241  1.000   8.283  1.000   8.326  1.000   8.368  1.000   8.411  1.000   8.453  1.000   8.496
1.000   8.538  1.000   8.581  1.000   8.623  1.000   8.666  1.000   8.708  1.000   8.751  1.000   8.793  1.000   8.836
1.000   8.878  1.000   8.920  1.000   8.963  1.000   9.005  1.000   9.048  1.000   9.090  1.000   9.133  1.000   9.175
1.000   9.218  1.000   9.260  1.000   9.303  1.000   9.345  1.000   9.388  1.000   9.430  1.000   9.473  1.000   9.515
1.000   9.558  1.000   9.600  1.000   9.643  1.000   9.685  1.000   9.728  1.000   9.770  1.000   9.813  1.000   9.855
1.000   9.898  1.000   9.940  1.000   9.983  1.000  10.025  1.000  10.067  1.000  10.110  1.000  10.152  1.000  10.195
1.000  10.237  1.000  10.280  1.000  10.322  1.000  10.365  1.000  10.407  1.000  10.450  1.000  10.492  1.000  10.535
1.000  10.577  1.000  10.620  1.000  10.662  1.000  10.705  1.000  10.747  1.000  10.790  1.000  10.832  1.000  10.875
1.000  10.917  1.000  10.960  1.000  11.002  1.000  11.045  1.000  11.087  1.000  11.129  1.000  11.172  1.000  11.214
1.000  11.257  1.000  11.299  1.000  11.342  1.000  11.384  1.000  11.427  1.000  11.469  1.000  11.512  1.000  11.554
1.000  11.597  1.000  11.639  1.000  11.682  1.000  11.724  1.000  11.767  1.000  11.809  1.000  11.852  1.000  11.894
1.000  11.937  1.000  11.979  1.000  12.022  1.000  12.064  1.000  12.107  1.000  12.149  1.000  12.192  1.000  12.234
1.000  12.276  1.000  12.319  1.000  12.361  1.000  12.404  1.000  12.446  1.000  12.489  1.000  12.531  1.000  12.574
1.000  12.616  1.000  12.659  1.000  12.701  1.000  12.744  1.000  12.786  1.000  12.829  1.000  12.871  1.000  12.914
1.000  12.956  1.000  12.999  1.000  13.041  1.000  13.084  1.000  13.126  1.000  13.169  1.000  13.211  1.000  13.254
1.000  13.296  1.000  13.338  1.000  13.381  1.000  13.423  1.000  13.466  1.000  13.508  1.000  13.551  1.000  13.593
1.000  13.636  1.000  13.678  1.000  13.721  1.000  13.763  1.000  13.806  1.000  13.848  1.000  13.891  1.000  13.933
1.000  13.976  1.000  14.018  1.000  14.061  1.000  14.103  1.000  14.146  1.000  14.188  1.000  14.231  1.000  14.273
1.000  14.316  1.000  14.358  1.000  14.401  1.000  14.443  1.000  14.485  1.000  14.528  1.000  14.570  1.000  14.613
1.000  14.655  1.000  14.698  1.000  14.740  1.000  14.783  1.000  14.825  1.000  14.868  1.000  14.910  1.000  14.953
1.000  14.995  1.000  15.038  1.000  15.080  1.000  15.123  1.000  15.165  1.000  15.208  1.000  15.250  1.000  15.293
1.000  15.335  1.000  15.378  1.000  15.420  1.000  15.463  1.000  15.505  1.000  15.548  1.000  15.590  1.000  15.632
1.000  15.675  1.000  15.717  1.000  15.760  1.000  15.802  1.000  15.845  1.000  15.887  1.000  15.930  1.000  15.972
1.000  16.015  1.000  16.057  1.000  16.100  1.000  16.142  1.000  16.185  1.000  16.227  1.000  16.270  1.000  16.312
1.000  16.355  1.000  16.397  1.000  16.440  1.000  16.482  1.000  16.525  1.000  16.567  1.000  16.610  1.000  16.652
1.000  16.694  1.000  16.737  1.000  16.779  1.000  16.822  1.000  16.864  1.000  16.907  1.000  16.949  1.000  16.992
1.000  17.034  1.000  17.077  1.000  17.119  1.000  17.162  1.000  17.204  1.000  17.247  1.000  17.289  1.000  17.332
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1.000  17.374   1.000  17.417   1.000  17.459   1.000  17.502   1.000  17.544   1.000  17.587   1.000  17.629   1.000  17.672
1.000  17.714   1.000  17.757   1.000  17.799   1.000  17.841   1.000  17.884   1.000  17.926   1.000  17.969   1.000  18.011
1.000  18.054   1.000  18.096   1.000  18.139   1.000  18.181   1.000  18.224   1.000  18.266   1.000  18.309   1.000  18.351
1.000  18.394   1.000  18.436   1.000  18.479   1.000  18.521   1.000  18.564   1.000  18.606   1.000  18.649   1.000  18.691
1.000  18.734   1.000  18.776   1.000  18.819   1.000  18.861   1.000  18.903   1.000  18.946   1.000  18.988   1.000  19.031
1.000  19.073   1.000  19.116   1.000  19.158   1.000  19.201   1.000  19.243   1.000  19.286   1.000  19.328   1.000  19.371
1.000  19.413   1.000  19.456   1.000  19.498   1.000  19.541   1.000  19.583   1.000  19.626   1.000  19.668   1.000  19.711
1.000  19.753   1.000  19.796   1.000  19.838   1.000  19.881   1.000  19.923   1.000  19.966   1.000  20.008   1.000  20.050
1.000  20.093   1.000  20.135   1.000  20.178   1.000  20.220   1.000  20.263   1.000  20.305   1.000  20.348   1.000  20.390
1.000  20.433   1.000  20.475   1.000  20.518   1.000  20.560   1.000  20.603   1.000  20.645   1.000  20.688   1.000  20.730
1.000  20.773   1.000  20.815   1.000  20.858   1.000  20.900   1.000  20.943   1.000  20.985   1.000  21.028   1.000  21.070
1.000  21.113   1.000  21.155   1.000  21.197   1.000  21.240   1.000  21.282   1.000  21.325   1.000  21.367   1.000  21.410
1.000  21.452   1.000  21.495   1.000  21.537   1.000  21.580   1.000  21.622   1.000  21.665   1.000  21.707   1.000  21.750
1.000  21.792   1.000  21.835   1.000  21.877   1.000  21.920   1.000  21.962   1.000  22.005   1.000  22.047   1.000  22.090
1.000  22.132   1.000  22.175   1.000  22.217   1.000  22.259   1.000  22.302   1.000  22.344   1.000  22.387   1.000  22.429
1.000  22.472   1.000  22.514   1.000  22.557   1.000  22.599   1.000  22.642   1.000  22.684   1.000  22.727   1.000  22.769
1.000  22.812   1.000  22.854   1.000  22.897   1.000  22.939   1.000  22.982   1.000  23.024   1.000  23.067   1.000  23.109
1.000  23.152   1.000  23.194   1.000  23.237   1.000  23.279   1.000  23.322   1.000  23.364   1.000  23.406   1.000  23.449
1.000  23.491   1.000  23.534   1.000  23.576   1.000  23.619   1.000  23.661   1.000  23.704   1.000  23.746   1.000  23.789
1.000  23.831   1.000  23.874   1.000  23.916   1.000  23.959   1.000  24.001   1.000  24.044   1.000  24.086   1.000  24.129
1.000  24.171   1.000  24.214   1.000  24.256   1.000  24.299   1.000  24.341   1.000  24.384   1.000  24.426   1.000  24.469
1.000  24.511   1.000  24.553   1.000  24.596   1.000  24.638   1.000  24.681   1.000  24.723   1.000  24.766   1.000  24.809
1.000  24.851   1.000  24.893   1.000  24.936   1.000  24.978   1.000  25.021   1.000  25.063   1.000  25.106   1.000  25.149
1.000  25.191   1.000  25.233   1.000  25.276   1.000  25.318   1.000  25.361   1.000  25.403   1.000  25.446   1.000  25.489
1.000  25.531   1.000  25.573   1.000  25.615   1.000  25.658   1.000  25.700   1.000  25.743   1.000  25.785   1.000  25.829
1.000  25.870   1.000  25.913   1.000  25.955   1.000  25.998   1.000  26.040   1.000  26.083   1.000  26.125   1.000  26.168
1.000  26.210   1.000  26.253   1.000  26.295   1.000  26.338   1.000  26.380   1.000  26.423   1.000  26.465   1.000  26.508
1.000  26.550   1.000  26.593   1.000  26.635   1.000  26.677   1.000  26.720   1.000  26.762   1.000  26.805   1.000  26.847
1.000  26.890   1.000  26.932   1.000  26.975   1.000  27.017   1.000  27.060   1.000  27.102   1.000  27.145   1.000  27.187
1.000  27.230   1.000  27.272   1.000  27.315   1.000  27.357   1.000  27.400   1.000  27.442   1.000  27.485   1.000  27.527
1.000  27.570   1.000  27.612   1.000  27.655   1.000  27.697   1.000  27.740   1.000  27.782   1.000  27.824   1.000  27.867
1.000  27.909   1.000  27.952   1.000  27.994   1.000  28.037   1.000  28.079   1.000  28.122   1.000  28.164   1.000  28.207
1.000  28.249   1.000  28.292   1.000  28.334   1.000  28.377   1.000  28.419   1.000  28.462   1.000  28.504   1.000  28.547
1.000  28.589   1.000  28.632   1.000  28.674   1.000  28.717   1.000  28.759   1.000  28.802   1.000  28.844   1.000  28.887
1.000  28.929   1.000  28.971   1.000  29.014   1.000  29.056   1.000  29.099   1.000  29.141   1.000  29.184   1.000  29.226
1.000  29.269   1.000  29.311   1.000  29.354   1.000  29.396   1.000  29.439   1.000  29.481   1.000  29.524   1.000  29.566
1.000  29.609   1.000  29.651   1.000  29.694   1.000  29.736   1.000  29.779   1.000  29.821   1.000  29.864   1.000  29.906
1.000  29.949   1.000  29.991   1.000  30.033   1.000  30.076   1.000  30.118   1.000  30.161   1.000  30.203   1.000  30.246
1.000  30.288   1.000  30.331   1.000  30.373   1.000  30.416   1.000  30.458   1.000  30.501   1.000  30.543   1.000  30.586
1.000  30.628   1.000  30.671   1.000  30.713   1.000  30.756   1.000  30.798   1.000  30.841   1.000  30.883   1.000  30.926
1.000  30.968   1.000  31.011   1.000  31.053   1.000  31.096   1.000  31.138   1.000  31.180   1.000  31.223   1.000  31.265
1.000  31.308   1.000  31.350   1.000  31.393   1.000  31.435   1.000  31.478   1.000  31.520   1.000  31.563   1.000  31.605
1.000  31.648   1.000  31.690   1.000  31.733   1.000  31.775   1.000  31.818   1.000  31.860   1.000  31.903   1.000  31.945
1.000  31.988   1.000  32.030   1.000  32.073   1.000  32.115   1.000  32.158   1.000  32.200   1.000  32.242   1.000  32.285
1.000  32.327   1.000  32.370   1.000  32.412   1.000  32.455   1.000  32.497   1.000  32.540   1.000  32.582   1.000  32.625
1.000  32.667   1.000  32.710   1.000  32.752   1.000  32.795   1.000  32.837   1.000  32.880   1.000  32.922   1.000  32.965
1.000  33.007   1.000  33.050   1.000  33.092   1.000  33.135   1.000  33.177   1.000  33.220   1.000  33.262   1.000  33.305
1.000  33.347   1.000  33.389   1.000  33.432   1.000  33.474   1.000  33.517   1.000  33.559   1.000  33.602   1.000  33.644
1.000  33.687   1.000  33.729   1.000  33.772   1.000  33.814   1.000  33.857   1.000  33.899   1.000  33.942   1.000  33.984
1.000  34.027   1.000  34.069   1.000  34.112   1.000  34.154   1.000  34.197   1.000  34.239   1.000  34.282   1.000  34.324
1.000  34.367   1.000  34.409   1.000  34.452   1.000  34.494   1.000  34.536   1.000  34.579   1.000  34.621   1.000  34.664
1.000  34.706   1.000  34.749   1.000  34.791   1.000  34.834   1.000  34.876   1.000  34.919   1.000  34.961   1.000  35.004
1.000  35.046   1.000  35.089   1.000  35.131   1.000  35.174   1.000  35.216   1.000  35.259   1.000  35.301   1.000  35.344
1.000  35.386   1.000  35.429   1.000  35.471   1.000  35.514   1.000  35.556   1.000  35.598   1.000  35.641   1.000  35.683
1.000  35.726   1.000  35.768   1.000  35.811   1.000  35.853   1.000  35.896   1.000  35.938   1.000  35.981   1.000  36.023
1.000  36.066   1.000  36.108   1.000  36.151   1.000  36.193   1.000  36.236   1.000  36.278   1.000  36.321   1.000  36.363
1.000  36.406   1.000  36.448   1.000  36.491   1.000  36.533   1.000  36.576   1.000  36.618   1.000  36.661   1.000  36.703
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1.000  36.745   2.000  36.798   2.000  36.830   2.000  36.873   2.000  36.915   2.000  36.958   2.000  37.000   2.000  37.043
2.000  37.085   2.000  37.128   2.000  37.170   2.000  37.213   2.000  37.255   2.000  37.298   2.000  37.340   2.000  37.383
2.000  37.425   2.000  37.468   2.000  37.510   2.000  37.553   2.000  37.595   2.000  37.638   2.000  37.680   2.000  37.723
2.000  37.765   2.000  37.807   2.000  37.850   2.000  37.892   2.000  37.935   2.000  37.977   2.000  38.020   2.000  38.062
2.000  38.105   2.000  38.147   2.000  38.190   2.000  38.232   2.000  38.275   2.000  38.317   2.000  38.360   2.000  38.402
2.000  38.445   2.000  38.487   2.000  38.530   2.000  38.572   2.000  38.615   2.000  38.657   2.000  38.700   2.000  38.742
2.000  38.785   2.000  38.827   2.000  38.870   2.000  38.912   2.000  38.954   2.000  38.997   2.000  39.039   2.000  39.082
2.000  39.124   2.000  39.167   2.000  39.209   2.000  39.252   2.000  39.294   2.000  39.337   2.000  39.379   2.000  39.422
2.000  39.464   2.000  39.507   2.000  39.549   2.000  39.592   2.000  39.634   2.000  39.677   2.000  39.719   2.000  39.762
2.000  39.804   2.000  39.847   2.000  39.889   2.000  39.932   2.000  39.974   2.000  40.016   2.000  40.059   2.000  40.101
2.000  40.144   2.000  40.186   2.000  40.229   2.000  40.271   2.000  40.314   2.000  40.356   2.000  40.399   2.000  40.441
2.000  40.484   2.000  40.526   2.000  40.569   2.000  40.611   2.000  40.654   2.000  40.696   2.000  40.739   2.000  40.781
2.000  40.824   2.000  40.866   2.000  40.909   2.000  40.951   2.000  40.994   2.000  41.036   2.000  41.079   2.000  41.121
2.000  41.163   2.000  41.206   2.000  41.248   2.000  41.291   2.000  41.333   2.000  41.376   2.000  41.418   2.000  41.461
2.000  41.503   2.000  41.546   2.000  41.588   2.000  41.631   2.000  41.673   2.000  41.716   2.000  41.758   2.000  41.801
2.000  41.843   2.000  41.886   2.000  41.928   2.000  41.971   2.000  42.013   2.000  42.056   2.000  42.098   2.000  42.141
2.000  42.183   2.000  42.226   2.000  42.268   2.000  42.310   2.000  42.353   2.000  42.395   2.000  42.438   2.000  42.480
2.000  42.523   2.000  42.565   2.000  42.608   2.000  42.650   2.000  42.693   2.000  42.735   2.000  42.778   2.000  42.820
2.000  42.863   2.000  42.905   2.000  42.948   2.000  42.990   2.000  43.033   2.000  43.075   2.000  43.118   2.000  43.160
2.000  43.203   2.000  43.245   2.000  43.288   2.000  43.330   2.000  43.372   2.000  43.415   2.000  43.457   2.000  43.500
2.000  43.542   2.000  43.585   2.000  43.627   2.000  43.670   2.000  43.712   2.000  43.755   2.000  43.797   2.000  43.840
2.000  43.882   2.000  43.925   2.000  43.967   2.000  44.010   2.000  44.052   2.000  44.095   2.000  44.137   2.000  44.180
2.000  44.222   2.000  44.265   2.000  44.307   2.000  44.350   2.000  44.392   2.000  44.435   2.000  44.477   2.000  44.519
2.000  44.562   2.000  44.604   2.000  44.647   2.000  44.689   2.000  44.732   2.000  44.774   2.000  44.817   2.000  44.859
2.000  44.902   2.000  44.944   2.000  44.987   2.000  45.029   2.000  45.072   2.000  45.114   2.000  45.157   2.000  45.199
2.000  45.242   2.000  45.284   2.000  45.327   2.000  45.369   2.000  45.412   2.000  45.454   2.000  45.497   2.000  45.539
2.000  45.581   2.000  45.624   2.000  45.666   2.000  45.709   2.000  45.751   2.000  45.794   2.000  45.836   2.000  45.879
2.000  45.921   2.000  45.964   2.000  46.006   2.000  46.049   2.000  46.091   2.000  46.134   2.000  46.176   2.000  46.219
2.000  46.261   2.000  46.304   2.000  46.346   2.000  46.389   2.000  46.431   2.000  46.474   2.000  46.516   2.000  46.559
2.000  46.601   2.000  46.644   2.000  46.686   2.000  46.728   2.000  46.771   2.000  46.813   2.000  46.856   2.000  46.899
2.000  46.941   2.000  46.983   2.000  47.026   2.000  47.068   2.000  47.111   2.000  47.153   2.000  47.196   2.000  47.238
2.000  47.281   2.000  47.323   2.000  47.366   2.000  47.408   2.000  47.451   2.000  47.493   2.000  47.536   2.000  47.578
2.000  47.621   2.000  47.663   2.000  47.706   2.000  47.748   2.000  47.791   2.000  47.833   2.000  47.875   2.000  47.918
2.000  47.960   2.000  48.003   2.000  48.045   2.000  48.088   2.000  48.130   2.000  48.173   2.000  48.215   2.000  48.258
2.000  48.300   2.000  48.343   2.000  48.385   2.000  48.428   2.000  48.470   2.000  48.513   2.000  48.555   2.000  48.598
2.000  48.640   2.000  48.683   2.000  48.725   2.000  48.768   2.000  48.810   2.000  48.853   2.000  48.895   2.000  48.937
2.000  48.980   2.000  49.022   2.000  49.065   2.000  49.107   2.000  49.150   2.000  49.192   2.000  49.235   2.000  49.277
2.000  49.320   2.000  49.362   2.000  49.405   2.000  49.447   2.000  49.490   2.000  49.532   2.000  49.575   2.000  49.617
2.000  49.660   2.000  49.702   2.000  49.745   2.000  49.787   2.000  49.830   2.000  49.872   2.000  49.915   2.000  49.957
2.000  50.000   2.000  50.042   2.000  50.084   2.000  50.127   2.000  50.169   2.000  50.212   2.000  50.254   2.000  50.297
2.000  50.339   2.000  50.382   2.000  50.424   2.000  50.467   2.000  50.509   2.000  50.552   2.000  50.594   2.000  50.637
2.000  50.679   2.000  50.722   2.000  50.764   2.000  50.807   2.000  50.849   2.000  50.892   2.000  50.934   2.000  50.977
2.000  51.019   2.000  51.062   2.000  51.104   2.000  51.146   2.000  51.189   2.000  51.231   2.000  51.274   2.000  51.316
2.000  51.359   2.000  51.401   2.000  51.444   2.000  51.486   2.000  51.529   2.000  51.571   2.000  51.614   2.000  51.656
2.000  51.699   2.000  51.741   2.000  51.784   2.000  51.826   2.000  51.869   2.000  51.911   2.000  51.954   2.000  51.995
2.000  52.039   2.000  52.081   2.000  52.124   2.000  52.166   2.000  52.209   2.000  52.251   2.000  52.293   2.000  52.335
2.000  52.378   2.000  52.421   2.000  52.463   2.000  52.506   2.000  52.548   2.000  52.591   2.000  52.633   2.000  52.675
2.000  52.718   2.000  52.761   2.000  52.803   2.000  52.846   2.000  52.888   2.000  52.931   2.000  52.973   2.000  53.015
2.000  53.058   2.000  53.101   2.000  53.143   2.000  53.186   2.000  53.228   2.000  53.271   2.000  53.313   2.000  53.355
2.000  53.398   2.000  53.440   2.000  53.483   2.000  53.525   2.000  53.568   2.000  53.610   2.000  53.653   2.000  53.695
2.000  53.738   2.000  53.780   2.000  53.823   2.000  53.865   2.000  53.908   2.000  53.950   2.000  53.993   2.000  54.035
2.000  54.078   2.000  54.120   2.000  54.163   2.000  54.205   2.000  54.248   2.000  54.290   2.000  54.333   2.000  54.375
2.000  54.418   2.000  54.460   2.000  54.502   2.000  54.545   2.000  54.587   2.000  54.630   2.000  54.672   3.000  54.715
3.000  54.757   3.000  54.800   3.000  54.842   3.000  54.885   3.000  54.927   3.000  54.970   3.000  55.012   3.000  55.055
3.000  55.097   3.000  55.140   3.000  55.182   3.000  55.225   3.000  55.267   3.000  55.310   3.000  55.352   3.000  55.395
3.000  55.437   3.000  55.480   3.000  55.522   3.000  55.565   3.000  55.607   3.000  55.649   3.000  55.692   3.000  55.734
3.000  55.777   3.000  55.819   3.000  55.862   3.000  55.904   3.000  55.947   3.000  55.989   3.000  56.032   3.000  56.074
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3.000  56.117   3.000  56.159   3.000  56.202   3.000  56.244   3.000  56.287   3.000  56.329   3.000  56.372   3.000  56.414
3.000  56.457   3.000  56.499   3.000  56.542   3.000  56.584   3.000  56.627   3.000  56.669   3.000  56.711   3.000  56.754
3.000  56.796   3.000  56.839   3.000  56.881   3.000  56.924   3.000  56.966   3.000  57.009   3.000  57.051   3.000  57.094
3.000  57.136   3.000  57.179   3.000  57.221   3.000  57.264   3.000  57.306   3.000  57.349   3.000  57.391   3.000  57.434
3.000  57.476   3.000  57.519   3.000  57.561   3.000  57.604   3.000  57.646   3.000  57.689   3.000  57.731   3.000  57.774
3.000  57.816   3.000  57.858   3.000  57.901   3.000  57.943   3.000  57.986   3.000  58.028   3.000  58.071   3.000  58.113
3.000  58.156   3.000  58.198   3.000  58.241   3.000  58.283   3.000  58.326   3.000  58.368   3.000  58.411   3.000  58.453
3.000  58.496   3.000  58.538   3.000  58.581   3.000  58.623   3.000  58.666   3.000  58.708   3.000  58.751   3.000  58.793
3.000  58.836   3.000  58.878   3.000  58.920   3.000  58.963   3.000  59.005   3.000  59.048   3.000  59.090   3.000  59.133
3.000  59.175   3.000  59.218   3.000  59.260   3.000  59.303   3.000  59.345   3.000  59.388   3.000  59.430   3.000  59.473
3.000  59.515   3.000  59.558   3.000  59.600   3.000  59.643   3.000  59.685   3.000  59.728   3.000  59.770   3.000  59.813
3.000  59.855   3.000  59.898   3.000  59.940   3.000  59.983   3.000  60.025   3.000  60.067   3.000  60.110   3.000  60.152
3.000  60.195   3.000  60.237   3.000  60.280   3.000  60.322   3.000  60.365   3.000  60.407   3.000  60.450   3.000  60.492
3.000  60.535   3.000  60.577   3.000  60.620   3.000  60.662   3.000  60.705   3.000  60.747   3.000  60.790   3.000  60.832
3.000  60.875   3.000  60.917   3.000  60.960   3.000  61.002   3.000  61.045   3.000  61.087   3.000  61.129   3.000  61.172
3.000  61.214   3.000  61.257   3.000  61.299   3.000  61.342   3.000  61.384   3.000  61.427   3.000  61.469   3.000  61.512
3.000  61.554   3.000  61.597   3.000  61.639   3.000  61.682   3.000  61.724   3.000  61.767   3.000  61.809   3.000  61.852
3.000  61.894   3.000  61.937   3.000  61.979   3.000  62.022   3.000  62.064   3.000  62.107   3.000  62.149   3.000  62.192
3.000  62.234   3.000  62.276   3.000  62.319   3.000  62.361   3.000  62.404   3.000  62.446   3.000  62.489   3.000  62.531
3.000  62.574   3.000  62.616   3.000  62.659   3.000  62.701   3.000  62.744   3.000  62.786   3.000  62.829   3.000  62.871
3.000  62.914   3.000  62.956   3.000  62.999   3.000  63.041   3.000  63.084   3.000  63.126   3.000  63.169   3.000  63.211
3.000  63.254   3.000  63.296   3.000  63.339   3.000  63.381   3.000  63.423   3.000  63.466   3.000  63.508   3.000  63.551
3.000  63.593   3.000  63.636   3.000  63.678   3.000  63.721   3.000  63.763   3.000  63.806   3.000  63.848   3.000  63.891
3.000  63.933   3.000  63.976   3.000  64.018   3.000  64.061   3.000  64.103   3.000  64.146   3.000  64.188   3.000  64.231
3.000  64.273   3.000  64.316   3.000  64.358   3.000  64.401   3.000  64.443   3.000  64.485   3.000  64.528   3.000  64.570
3.000  64.613   4.000  64.655   4.000  64.698   4.000  64.740   4.000  64.783   4.000  64.825   4.000  64.868   4.000  64.910
4.000  64.953   4.000  64.995   4.000  65.038   4.000  65.080   4.000  65.123   4.000  65.165   4.000  65.208   4.000  65.250
4.000  65.293   4.000  65.335   4.000  65.378   4.000  65.420   4.000  65.463   4.000  65.505   4.000  65.548   4.000  65.590
4.000  65.632   4.000  65.675   4.000  65.717   4.000  65.760   4.000  65.802   4.000  65.845   4.000  65.887   4.000  65.930
4.000  65.972   4.000  66.015   4.000  66.057   4.000  66.100   4.000  66.142   4.000  66.185   4.000  66.227   4.000  66.270
4.000  66.312   4.000  66.355   4.000  66.397   4.000  66.440   4.000  66.482   4.000  66.525   4.000  66.567   4.000  66.610
4.000  66.652   4.000  66.694   4.000  66.737   4.000  66.779   4.000  66.822   4.000  66.864   4.000  66.907   4.000  66.949
4.000  66.992   4.000  67.034   4.000  67.077   4.000  67.119   4.000  67.162   4.000  67.204   4.000  67.247   4.000  67.289
4.000  67.332   4.000  67.374   4.000  67.417   4.000  67.459   4.000  67.502   4.000  67.544   4.000  67.587   4.000  67.629
4.000  67.672   4.000  67.714   4.000  67.757   4.000  67.799   4.000  67.841   4.000  67.884   4.000  67.926   4.000  67.969
4.000  68.011   4.000  68.054   4.000  68.096   4.000  68.139   4.000  68.181   4.000  68.224   4.000  68.266   4.000  68.309
4.000  68.351   4.000  68.394   4.000  68.436   4.000  68.479   4.000  68.521   4.000  68.564   4.000  68.606   4.000  68.649
4.000  68.691   4.000  68.734   4.000  68.776   4.000  68.819   4.000  68.861   4.000  68.904   4.000  68.946   4.000  68.988
4.000  69.031   4.000  69.073   4.000  69.116   4.000  69.159   4.000  69.201   4.000  69.243   4.000  69.286   4.000  69.328
4.000  69.371   4.000  69.413   4.000  69.456   4.000  69.498   4.000  69.541   4.000  69.583   4.000  69.626   4.000  69.668
4.000  69.711   4.000  69.753   4.000  69.796   4.000  69.838   4.000  69.881   4.000  69.923   4.000  69.966   4.000  70.008
4.000  70.050   4.000  70.093   4.000  70.135   4.000  70.178   4.000  70.220   4.000  70.263   4.000  70.305   4.000  70.348
4.000  70.390   4.000  70.433   4.000  70.475   4.000  70.518   4.000  70.560   4.000  70.603   4.000  70.645   4.000  70.688
4.000  70.730   4.000  70.773   4.000  70.815   4.000  70.858   4.000  70.900   4.000  70.943   4.000  70.985   4.000  71.028
4.000  71.070   4.000  71.113   4.000  71.155   4.000  71.197   4.000  71.240   4.000  71.282   4.000  71.325   4.000  71.367
4.000  71.410   4.000  71.452   4.000  71.495   4.000  71.537   4.000  71.580   4.000  71.622   4.000  71.665   4.000  71.707
5.000  71.750   5.000  71.792   5.000  71.835   5.000  71.877   5.000  71.920   5.000  71.962   5.000  72.005   5.000  72.047
5.000  72.090   5.000  72.132   5.000  72.175   5.000  72.217   5.000  72.259   5.000  72.302   5.000  72.344   5.000  72.387
5.000  72.429   5.000  72.472   5.000  72.514   5.000  72.557   5.000  72.599   5.000  72.642   5.000  72.684   5.000  72.727
5.000  72.769   5.000  72.812   5.000  72.854   5.000  72.897   5.000  72.939   5.000  72.982   5.000  73.024   5.000  73.067
5.000  73.109   5.000  73.152   5.000  73.194   5.000  73.237   5.000  73.279   5.000  73.322   5.000  73.364   5.000  73.406
5.000  73.449   5.000  73.491   5.000  73.534   5.000  73.576   5.000  73.619   5.000  73.661   5.000  73.704   5.000  73.746
5.000  73.789   5.000  73.831   5.000  73.874   5.000  73.916   5.000  73.959   5.000  74.001   5.000  74.044   5.000  74.086
5.000  74.129   5.000  74.171   5.000  74.214   5.000  74.256   5.000  74.299   5.000  74.341   5.000  74.384   5.000  74.426
5.000  74.468   5.000  74.511   5.000  74.553   5.000  74.596   5.000  74.638   5.000  74.681   5.000  74.723   5.000  74.766
5.000  74.808   5.000  74.851   5.000  74.893   5.000  74.936   5.000  74.978   5.000  75.021   5.000  75.063   5.000  75.106
5.000  75.148   5.000  75.191   5.000  75.233   5.000  75.276   5.000  75.318   5.000  75.361   5.000  75.403   5.000  75.445
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 5.000  75.488   5.000  75.531   5.000  75.573   5.000  75.615   5.000  75.658   5.000  75.700   5.000  75.743   5.000  75.785
 5.000  75.828   5.000  75.870   5.000  75.913   5.000  75.955   5.000  75.998   5.000  76.040   5.000  76.083   5.000  76.125
 5.000  76.168   5.000  76.210   5.000  76.253   5.000  76.295   5.000  76.338   5.000  76.380   5.000  76.423   5.000  76.465
 5.000  76.508   5.000  76.550   5.000  76.593   5.000  76.635   5.000  76.678   5.000  76.720   6.000  76.762   6.000  76.805
 6.000  76.847   6.000  76.890   6.000  76.932   6.000  76.975   6.000  77.017   6.000  77.060   6.000  77.102   6.000  77.145
 6.000  77.187   6.000  77.230   6.000  77.272   6.000  77.315   6.000  77.357   6.000  77.400   6.000  77.442   6.000  77.485
 6.000  77.527   6.000  77.570   6.000  77.612   6.000  77.655   6.000  77.697   6.000  77.740   6.000  77.782   6.000  77.824
 6.000  77.867   6.000  77.909   6.000  77.952   6.000  77.994   6.000  78.037   6.000  78.079   6.000  78.122   6.000  78.164
 6.000  78.207   6.000  78.249   6.000  78.292   6.000  78.334   6.000  78.377   6.000  78.419   6.000  78.462   6.000  78.504
 6.000  78.547   6.000  78.589   6.000  78.632   6.000  78.674   6.000  78.717   6.000  78.759   6.000  78.802   6.000  78.844
 6.000  78.887   6.000  78.929   6.000  78.971   6.000  79.014   6.000  79.056   6.000  79.099   6.000  79.141   6.000  79.184
 6.000  79.226   6.000  79.269   6.000  79.311   6.000  79.354   6.000  79.396   6.000  79.439   6.000  79.481   6.000  79.524
 6.000  79.566   6.000  79.609   6.000  79.651   6.000  79.694   6.000  79.736   6.000  79.779   6.000  79.821   6.000  79.864
 6.000  79.906   6.000  79.949   6.000  79.991   7.000  80.033   7.000  80.076   7.000  80.118   7.000  80.161   7.000  80.203
 7.000  80.246   7.000  80.288   7.000  80.331   7.000  80.373   7.000  80.416   7.000  80.458   7.000  80.501   7.000  80.543
 7.000  80.586   7.000  80.628   7.000  80.671   7.000  80.713   7.000  80.756   7.000  80.798   7.000  80.841   7.000  80.883
 7.000  80.926   7.000  80.968   7.000  81.011   7.000  81.053   7.000  81.096   7.000  81.138   7.000  81.180   7.000  81.223
 7.000  81.265   7.000  81.308   7.000  81.350   7.000  81.393   7.000  81.435   7.000  81.478   7.000  81.520   7.000  81.563
 7.000  81.605   7.000  81.648   7.000  81.690   7.000  81.733   7.000  81.775   7.000  81.818   7.000  81.860   7.000  81.903
 7.000  81.945   7.000  81.988   7.000  82.030   7.000  82.073   7.000  82.115   7.000  82.158   7.000  82.200   7.000  82.242
 7.000  82.285   7.000  82.327   7.000  82.370   7.000  82.412   7.000  82.455   7.000  82.497   7.000  82.540   7.000  82.582
 7.000  82.625   7.000  82.667   7.000  82.710   7.000  82.752   7.000  82.795   7.000  82.837   7.000  82.880   7.000  82.922
 7.000  82.965   7.000  83.007   7.000  83.050   7.000  83.092   7.000  83.135   8.000  83.177   8.000  83.220   8.000  83.262
 8.000  83.305   8.000  83.347   8.000  83.389   8.000  83.432   8.000  83.474   8.000  83.517   8.000  83.559   8.000  83.602
 8.000  83.644   8.000  83.687   8.000  83.729   8.000  83.772   8.000  83.814   8.000  83.857   8.000  83.899   8.000  83.942
 8.000  83.984   8.000  84.027   8.000  84.069   8.000  84.112   8.000  84.154   8.000  84.197   8.000  84.239   8.000  84.282
 8.000  84.324   8.000  84.367   8.000  84.409   8.000  84.452   8.000  84.494   8.000  84.536   8.000  84.579   8.000  84.621
 8.000  84.664   8.000  84.706   8.000  84.749   8.000  84.791   8.000  84.834   8.000  84.876   8.000  84.919   8.000  84.961
 8.000  85.004   9.000  85.046   8.000  85.089   8.000  85.131   8.000  85.174   9.000  85.216   9.000  85.259   9.000  85.301
 9.000  85.344   9.000  85.386   9.000  85.429   9.000  85.471   9.000  85.514   9.000  85.556   9.000  85.598   9.000  85.641
 9.000  85.683   9.000  85.726   9.000  85.768   9.000  85.811   9.000  85.853   9.000  85.896   9.000  85.938   9.000  85.981
 9.000  86.023   9.000  86.066   9.000  86.108   9.000  86.151   9.000  86.193   9.000  86.236   9.000  86.278   9.000  86.321
 9.000  86.363   9.000  86.406   9.000  86.448   9.000  86.491   9.000  86.533   9.000  86.576   9.000  86.618   9.000  86.661
 9.000  86.703   9.000  86.745   9.000  86.788   9.000  86.830   9.000  86.873   9.000  86.915   9.000  86.958   9.000  87.000
 9.000  87.043   9.000  87.085   9.000  87.128   9.000  87.170   9.000  87.213   9.000  87.255  10.000  87.298  10.000  87.340
10.000  87.383  10.000  87.425  10.000  87.468  10.000  87.510  10.000  87.553  10.000  87.595  10.000  87.638  10.000  87.680
10.000  87.723  10.000  87.765  10.000  87.807  10.000  87.850  10.000  87.892  10.000  87.935  10.000  87.977  10.000  88.020
10.000  88.062  10.000  88.105  10.000  88.147  10.000  88.190  10.000  88.232  10.000  88.275  10.000  88.317  10.000  88.360
10.000  88.402  10.000  88.445  10.000  88.487  10.000  88.530  10.000  88.572  10.000  88.615  10.000  88.657  10.000  88.700
10.000  88.742  10.000  88.785  10.000  88.827  10.000  88.870  10.000  88.912  10.000  88.954  10.000  88.997  10.000  89.039
10.000  89.082  10.000  89.124  10.000  89.167  11.000  89.209  11.000  89.252  11.000  89.294  11.000  89.337  11.000  89.379
11.000  89.422  11.000  89.464  11.000  89.507  11.000  89.549  11.000  89.592  11.000  89.634  11.000  89.677  11.000  89.719
11.000  89.762  11.000  89.804  11.000  89.847  11.000  89.889  11.000  89.932  11.000  89.974  11.000  90.016  11.000  90.059
11.000  90.101  11.000  90.144  11.000  90.186  11.000  90.229  11.000  90.271  11.000  90.314  11.000  90.356  11.000  90.399
12.000  90.441  12.000  90.484  12.000  90.526  12.000  90.569  12.000  90.611  12.000  90.654  12.000  90.696  12.000  90.739
12.000  90.781  12.000  90.824  12.000  90.866  12.000  90.909  12.000  90.951  12.000  90.994  12.000  91.036  12.000  91.079
12.000  91.121  12.000  91.163  12.000  91.206  12.000  91.248  12.000  91.291  12.000  91.333  12.000  91.376  12.000  91.419
13.000  91.461  13.000  91.503  13.000  91.546  13.000  91.588  13.000  91.631  13.000  91.673  13.000  91.716  13.000  91.759
13.000  91.801  13.000  91.843  13.000  91.886  13.000  91.928  13.000  91.971  13.000  92.013  13.000  92.056  13.000  92.098
13.000  92.141  13.000  92.183  13.000  92.226  13.000  92.268  13.000  92.310  13.000  92.353  13.000  92.395  13.000  92.438
13.000  92.480  13.000  92.523  13.000  92.565  14.000  92.608  14.000  92.650  14.000  92.693  14.000  92.735  14.000  92.778
14.000  92.820  14.000  92.863  14.000  92.905  14.000  92.948  14.000  92.990  14.000  93.033  14.000  93.075  14.000  93.118
14.000  93.160  14.000  93.203  14.000  93.245  14.000  93.288  14.000  93.330  14.000  93.372  14.000  93.415  14.000  93.457
14.000  93.500  15.000  93.542  15.000  93.585  15.000  93.627  15.000  93.670  15.000  93.712  15.000  93.755  15.000  93.797
15.000  93.840  15.000  93.882  15.000  93.925  15.000  93.967  15.000  94.010  15.000  94.052  15.000  94.095  15.000  94.137
15.000  94.180  15.000  94.222  15.000  94.265  15.000  94.307  16.000  94.350  16.000  94.392  16.000  94.435  16.000  94.477
16.000  94.519  16.000  94.562  16.000  94.604  16.000  94.647  16.000  94.689  16.000  94.732  16.000  94.774  16.000  94.817
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16.000  94.859  17.000  94.902  17.000  94.944  17.000  94.987  17.000  95.029  17.000  95.072  17.000  95.114  17.000  95.157
17.000  95.199  17.000  95.242  17.000  95.284  17.000  95.327  17.000  95.369  17.000  95.412  18.000  95.454  18.000  95.497
18.000  95.539  18.000  95.582  18.000  95.624  18.000  95.666  18.000  95.709  18.000  95.751  18.000  95.794  18.000  95.836
18.000  95.879  18.000  95.921  18.000  95.964  19.000  96.006  19.000  96.049  19.000  96.091  19.000  96.134  19.000  96.176
19.000  96.219  19.000  96.261  19.000  96.304  19.000  96.346  19.000  96.389  19.000  96.431  19.000  96.474  19.000  96.516
20.000  96.559  20.000  96.601  20.000  96.644  20.000  96.686  20.000  96.728  20.000  96.771  20.000  96.813  20.000  96.856
21.000  96.898  21.000  96.941  21.000  96.983  21.000  97.026  21.000  97.068  21.000  97.111  21.000  97.153  21.000  97.196
22.000  97.238  22.000  97.281  22.000  97.323  22.000  97.366  22.000  97.408  22.000  97.451  22.000  97.493  22.000  97.536
22.000  97.578  22.000  97.621  23.000  97.663  23.000  97.706  23.000  97.748  23.000  97.791  23.000  97.833  23.000  97.875
24.000  97.918  24.000  97.960  24.000  98.003  24.000  98.045  24.000  98.088  25.000  98.130  25.000  98.173  25.000  98.215
25.000  98.258  25.000  98.300  25.000  98.343  25.000  98.385  25.000  98.428  25.000  98.470  26.000  98.513  26.000  98.555
26.000  98.598  27.000  98.640  27.000  98.683  27.000  98.725  27.000  98.768  27.000  98.810  27.000  98.853  28.000  98.895
28.000  98.937  29.000  98.930  29.000  99.022  29.000  99.065  29.000  99.107  29.000  99.150  30.000  99.192  30.000  99.235
31.000  99.277  32.000  99.320  33.000  99.362  33.000  99.405  33.000  99.447  33.000  99.490  35.000  99.532  36.000  99.575
36.000  99.617  37.000  99.650  37.000  99.702  37.000  99.745  39.000  99.787  40.000  99.830  42.000  99.872  46.000  99.915
49.000  99.957  58.000 100.000
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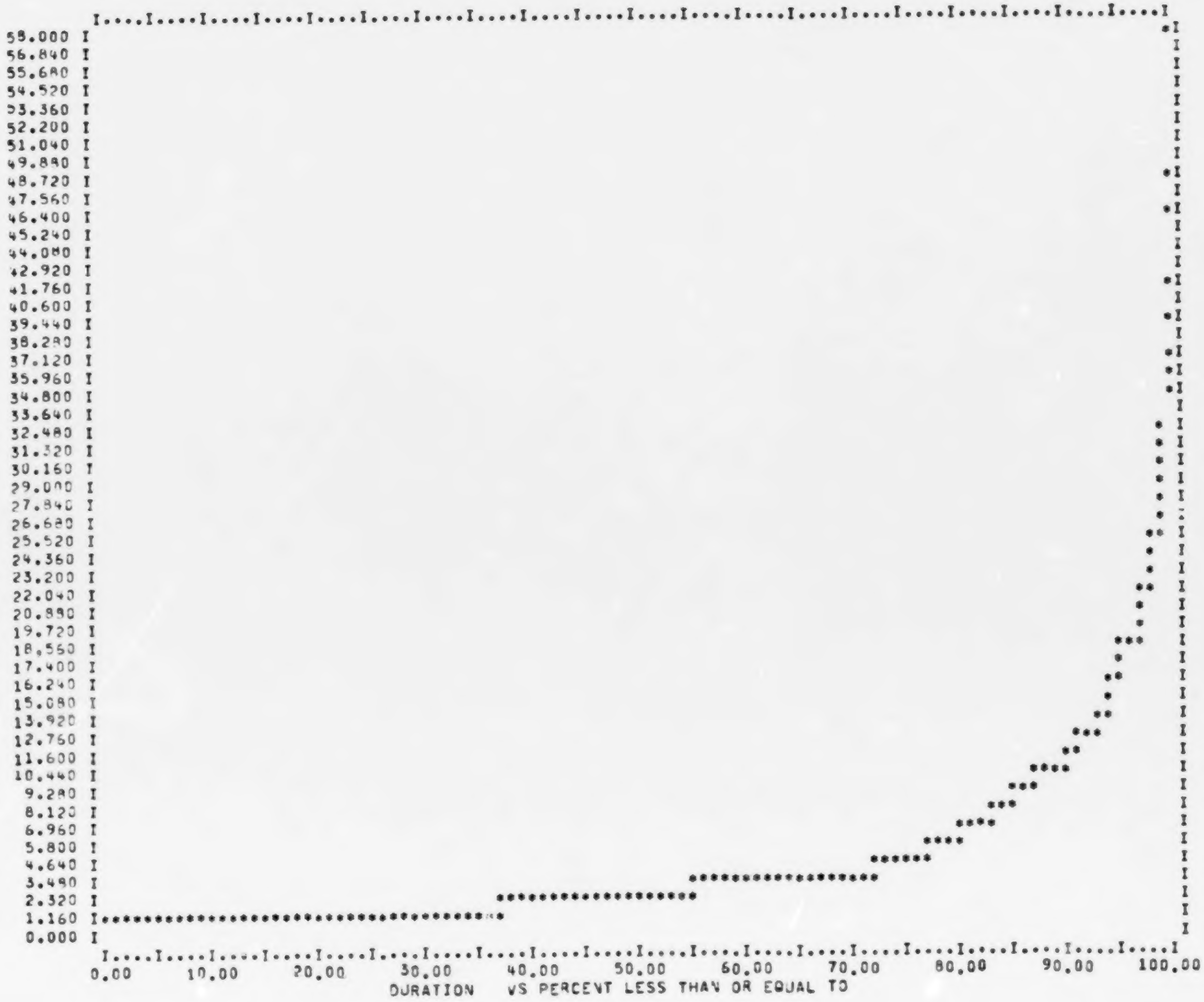
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50.00
60.00
70.00
80.00
90.00
100.00
DURATION VS PERCENT LESS THAN OR EQUAL TO

RETURN PERIOD (IN YEARS) FOR DURATION

```
 VALUE   PERIOD    VALUE   PERIOD    VALUE   PERIOD    VALUE   PERIOD    VALUE   PERIOD    VALUE   PERIOD    VALUE   PERIOD    VALUE   PERIOD
58.000   26.000   49.000   13.000   46.000    8.666   42.000    6.500   40.000    5.200   39.000    4.333   37.000    3.714   37.000    3.250
37.000    2.888   36.000    2.600   36.000    2.363   35.000    2.166   33.000    2.000   33.000    1.857   33.000    1.733   33.000    1.625
32.000    1.529   31.000    1.444   30.000    1.368   30.000    1.300   29.000    1.238   29.000    1.181   29.000    1.130   29.000    1.083
29.000    1.040   28.000    1.000   28.000    0.962   27.000    0.928   27.000    0.896   27.000    0.866   27.000    0.838   27.000    0.812
27.000    0.787   26.000    0.764   26.000    0.742   26.000    0.722   25.000    0.702   25.000    0.684   25.000    0.666   25.000    0.650
25.000    0.634   25.000    0.619   25.000    0.604   25.000    0.590   25.000    0.577   24.000    0.565   24.000    0.553   24.000    0.541
24.000    0.530   24.000    0.520   23.000    0.509   23.000    0.500   23.000    0.490   23.000    0.481   23.000    0.472   23.000    0.464
22.000    0.456   22.000    0.448   22.000    0.440   22.000    0.433   22.000    0.426   22.000    0.419   22.000    0.412   22.000    0.406
22.000    0.400   22.000    0.393   21.000    0.388   21.000    0.382   21.000    0.376   21.000    0.371   21.000    0.366   21.000    0.361
21.000    0.356   21.000    0.351   20.000    0.346   20.000    0.342   20.000    0.337   20.000    0.333   20.000    0.329   20.000    0.325
20.000    0.320   20.000    0.317   19.000    0.313   19.000    0.309   19.000    0.305   19.000    0.302   19.000    0.298   19.000    0.295
19.000    0.292   19.000    0.288   19.000    0.285   19.000    0.282   19.000    0.279   19.000    0.276   19.000    0.273   18.000    0.270
18.000    0.268   18.000    0.265   18.000    0.262   18.000    0.260   18.000    0.257   18.000    0.254   18.000    0.252   18.000    0.250
18.000    0.247   18.000    0.245   18.000    0.242   18.000    0.240   17.000    0.238   17.000    0.236   17.000    0.234   17.000    0.232
17.000    0.230   17.000    0.228   17.000    0.226   17.000    0.224   17.000    0.222   17.000    0.220   17.000    0.218   17.000    0.216
17.000    0.214   16.000    0.213   16.000    0.211   16.000    0.209   16.000    0.208   16.000    0.206   16.000    0.204   16.000    0.203
16.000    0.201   16.000    0.200   16.000    0.198   16.000    0.196   16.000    0.195   16.000    0.194   15.000    0.192   15.000    0.191
15.000    0.189   15.000    0.188   15.000    0.187   15.000    0.185   15.000    0.184   15.000    0.183   15.000    0.181   15.000    0.180
15.000    0.179   15.000    0.178   15.000    0.176   15.000    0.175   15.000    0.174   15.000    0.173   15.000    0.172   15.000    0.171
15.000    0.169   14.000    0.168   14.000    0.167   14.000    0.166   14.000    0.165   14.000    0.164   14.000    0.163   14.000    0.162
14.000    0.161   14.000    0.160   14.000    0.159   14.000    0.158   14.000    0.157   14.000    0.156   14.000    0.155   14.000    0.154
14.000    0.153   14.000    0.152   14.000    0.152   14.000    0.151   14.000    0.150   14.000    0.149   14.000    0.148   13.000    0.147
13.000    0.146   13.000    0.146   13.000    0.145   13.000    0.144   13.000    0.143   13.000    0.142   13.000    0.142   13.000    0.141
13.000    0.140   13.000    0.139   13.000    0.139   13.000    0.138   13.000    0.137   13.000    0.136   13.000    0.136   13.000    0.135
13.000    0.134   13.000    0.134   13.000    0.133   13.000    0.132   13.000    0.131   13.000    0.131   13.000    0.130   13.000    0.130
13.000    0.129   13.000    0.128   12.000    0.128   12.000    0.127   12.000    0.126   12.000    0.126   12.000    0.125   12.000    0.125
12.000    0.124   12.000    0.123   12.000    0.123   12.000    0.122   12.000    0.122   12.000    0.121   12.000    0.120   12.000    0.120
12.000    0.119   12.000    0.119   12.000    0.118   12.000    0.118   12.000    0.117   12.000    0.117   12.000    0.116   12.000    0.116
12.000    0.115   12.000    0.115   11.000    0.114   11.000    0.114   11.000    0.113   11.000    0.113   11.000    0.112   11.000    0.112
11.000    0.111   11.000    0.111   11.000    0.110   11.000    0.110   11.000    0.109   11.000    0.109   11.000    0.108   11.000    0.108
11.000    0.107   11.000    0.107   11.000    0.106   11.000    0.106   11.000    0.106   11.000    0.105   11.000    0.105   11.000    0.104
11.000    0.104   11.000    0.104   11.000    0.103   11.000    0.103   11.000    0.102   11.000    0.102   11.000    0.101   10.000    0.101
10.000    0.101   10.000    0.100   10.000    0.100   10.000    0.100   10.000    0.099   10.000    0.099   10.000    0.098   10.000    0.098
10.000    0.098   10.000    0.097   10.000    0.097   10.000    0.097   10.000    0.096   10.000    0.096   10.000    0.095   10.000    0.095
10.000    0.095   10.000    0.094   10.000    0.094   10.000    0.094   10.000    0.093   10.000    0.093   10.000    0.093   10.000    0.092
10.000    0.092   10.000    0.092   10.000    0.091   10.000    0.091   10.000    0.091   10.000    0.090   10.000    0.090   10.000    0.090
10.000    0.089   10.000    0.089   10.000    0.089   10.000    0.089   10.000    0.088   10.000    0.088   10.000    0.088   10.000    0.087
10.000    0.087   10.000    0.087   10.000    0.086   10.000    0.086    9.000    0.086    9.000    0.086    9.000    0.085    9.000    0.085
 9.000    0.085    9.000    0.084    9.000    0.084    9.000    0.084    9.000    0.084    9.000    0.083    9.000    0.083    9.000    0.083
 9.000    0.083    9.000    0.082    9.000    0.082    9.000    0.082    9.000    0.082    9.000    0.081    9.000    0.081    9.000    0.081
 9.000    0.080    9.000    0.080    9.000    0.080    9.000    0.080    9.000    0.080    9.000    0.079    9.000    0.079    9.000    0.079
 9.000    0.079    9.000    0.078    9.000    0.078    9.000    0.078    9.000    0.078    9.000    0.077    9.000    0.077    9.000    0.077
 9.000    0.077    9.000    0.076    9.000    0.076    9.000    0.076    9.000    0.076    9.000    0.076    9.000    0.075    9.000    0.075
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 7.000    0.062    7.000    0.062    7.000    0.062    7.000    0.061    7.000    0.061    7.000    0.061    7.000    0.061    7.000    0.061
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7.000   0.060   7.000   0.059   7.000   0.059   7.000   0.059   7.000   0.059   7.000   0.059   7.000   0.059   7.000   0.059
7.000   0.058   7.000   0.058   7.000   0.058   7.000   0.058   7.000   0.058   7.000   0.058   7.000   0.058   7.000   0.058
7.000   0.057   7.000   0.057   7.000   0.057   7.000   0.057   7.000   0.057   7.000   0.057   7.000   0.057   7.000   0.057
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7.000   0.055   7.000   0.055   7.000   0.055   7.000   0.055   7.000   0.055   7.000   0.055   7.000   0.055   6.000   0.055
6.000   0.054   6.000   0.054   6.000   0.054   6.000   0.054   6.000   0.054   6.000   0.054   6.000   0.054   6.000   0.054
6.000   0.054   6.000   0.053   6.000   0.053   6.000   0.053   6.000   0.053   6.000   0.053   6.000   0.053   6.000   0.053
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6.000   0.050   6.000   0.050   6.000   0.050   6.000   0.050   6.000   0.050   6.000   0.050   6.000   0.050   6.000   0.050
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6.000   0.048   6.000   0.048   6.000   0.048   6.000   0.048   6.000   0.048   6.000   0.047   6.000   0.047   6.000   0.047
6.000   0.047   6.000   0.047   6.000   0.047   6.000   0.047   5.000   0.047   5.000   0.047   5.000   0.047   5.000   0.047
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5.000   0.043   5.000   0.043   5.000   0.043   5.000   0.043   5.000   0.042   5.000   0.042   5.000   0.042   5.000   0.042
5.000   0.042   5.000   0.042   5.000   0.042   5.000   0.042   5.000   0.042   5.000   0.042   5.000   0.042   5.000   0.042
5.000   0.042   5.000   0.042   5.000   0.042   5.000   0.041   5.000   0.041   5.000   0.041   5.000   0.041   5.000   0.041
5.000   0.041   5.000   0.041   5.000   0.041   5.000   0.041   5.000   0.041   5.000   0.041   5.000   0.041   5.000   0.041
5.000   0.041   5.000   0.041   5.000   0.040   5.000   0.040   5.000   0.040   5.000   0.040   5.000   0.040   5.000   0.040
5.000   0.040   5.000   0.040   5.000   0.040   5.000   0.040   5.000   0.040   5.000   0.040   5.000   0.040   5.000   0.040
5.000   0.040   5.000   0.040   5.000   0.039   5.000   0.039   5.000   0.039   5.000   0.039   5.000   0.039   5.000   0.039
5.000   0.039   5.000   0.039   5.000   0.039   5.000   0.039   5.000   0.039   5.000   0.039   5.000   0.039   5.000   0.039
5.000   0.039   5.000   0.039   4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.038
4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.038
4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.038   4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.037
4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.037
4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.037   4.000   0.036   4.000   0.036
4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.036
4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.036   4.000   0.035
4.000   0.036   4.000   0.036   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035
4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035
4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.035   4.000   0.034   4.000   0.034
4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034
4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034
4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.034   4.000   0.033   4.000   0.033   4.000   0.033   4.000   0.033
4.000   0.033   4.000   0.033   4.000   0.033   4.000   0.033   4.000   0.033   4.000   0.033   4.000   0.033   4.000   0.033
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4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032
4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032
4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.032   4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031
4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031
4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031   4.000   0.031
4.000   0.031   3.000   0.031   3.000   0.031   3.000   0.031   3.000   0.031   3.000   0.031   3.000   0.030   3.000   0.030
3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030
3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030
3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030   3.000   0.030
3.000   0.030   3.000   0.030   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029
3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029
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3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029
3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029   3.000   0.029
3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028
3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028
3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028
3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028   3.000   0.028
3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027
3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027
3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027
3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027   3.000   0.027
3.000   0.027   3.000   0.027   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026
3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026
3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026
3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026   3.000   0.026
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3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025
3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025
3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025
3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025
3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025   3.000   0.025
3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024
3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024
3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024   3.000   0.024
3.000   0.024   3.000   0.024   3.000   0.024   2.000   0.024   2.000   0.024   2.000   0.024   2.000   0.024   2.000   0.024
2.000   0.024   2.000   0.024   2.000   0.024   2.000   0.024   2.000   0.024   2.000   0.024   2.000   0.024   2.000   0.024
2.000   0.024   2.000   0.024   2.000   0.024   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023
2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023
2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023
2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023
2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023
2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023   2.000   0.023
2.000   0.023   2.000   0.023   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022
2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022
2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022
2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022
2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022
2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022
2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.022   2.000   0.021   2.000   0.021   2.000   0.021
2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021
2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021
2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021
2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021
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2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021
2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.021   2.000   0.020   2.000   0.020
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2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020
2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020
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2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.020   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019
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2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019
2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019
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2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019   2.000   0.019
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2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018
2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018
2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018
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2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018
2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018   2.000   0.018
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2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017
2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017
2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017
2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017
2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017   2.000   0.017
2.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017
1.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017   1.000   0.017
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1.000   0.016   1.000   0.016   1.000   0.016   1.000   0.016   1.000   0.016   1.000   0.016   1.000   0.016   1.000   0.016
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1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
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1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
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1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014   1.000   0.014
1.000   0.014   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
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1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
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1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013   1.000   0.013
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
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1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012
1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.012   1.000   0.011   1.000   0.011
1.000   0.011   1.000   0.011   1.000   0.011   1.000   0.011   1.000   0.011   1.000   0.011   1.000   0.011   1.000   0.011
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1.000    0.011    1.000    0.011    1.000    0.011    1.000    0.011    1.000    0.011    1.000    0.011    1.000    0.011    1.000    0.011
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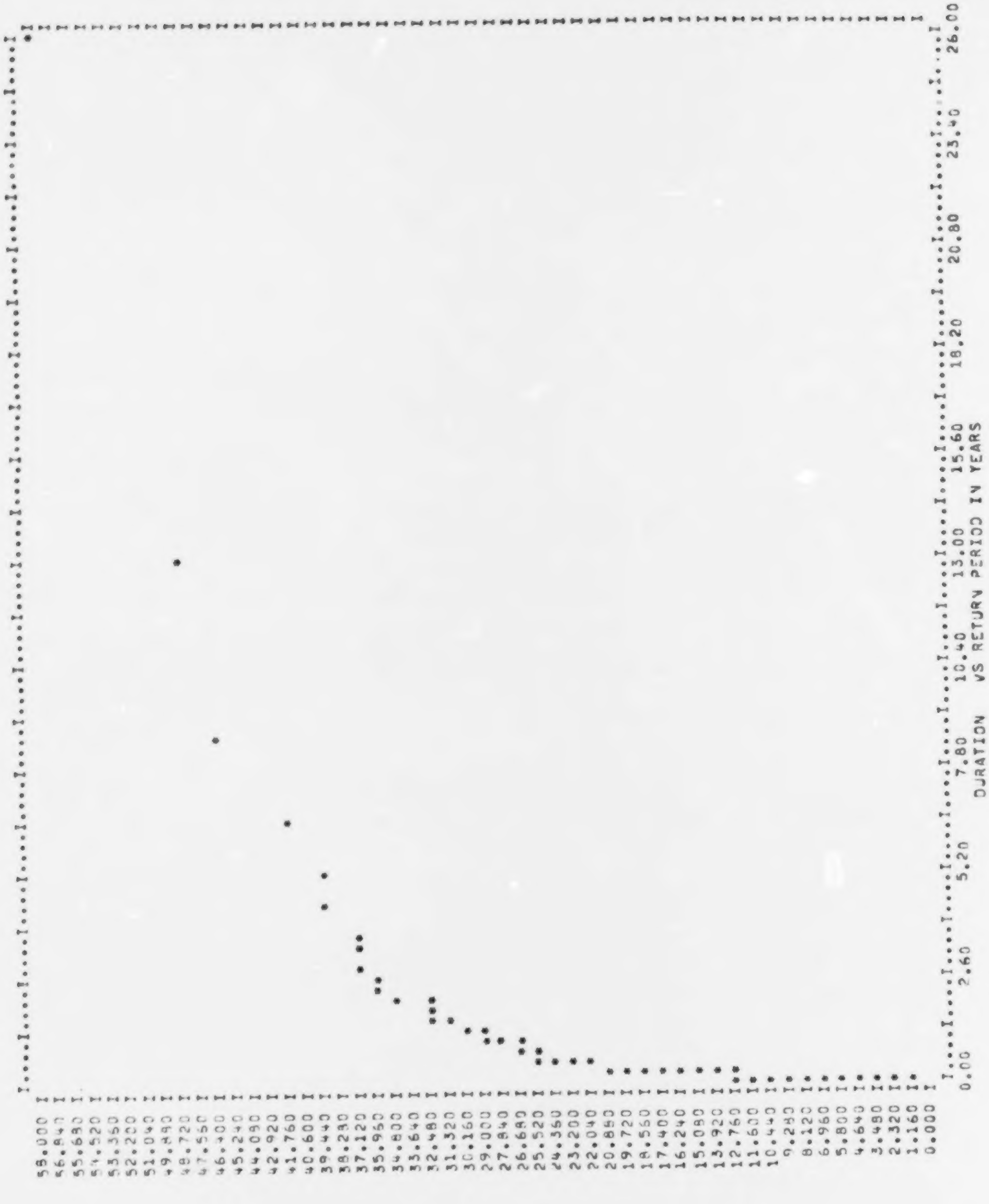
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2.60
5.20
7.80
10.40
13.00
15.60
18.20
20.80
23.40
26.00
DURATION VS RETURN PERIOD IN YEARS

PROBABILITY ANALYSIS-INTENSITY

PERCENTAGE OF OCCURRENCE LESS THAN OR EQUAL TO THE GIVEN VALJE OF INTENSITY

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VALJE     PCT   VALUE     PCT   VALJE     PCT   VALJE     PCT   VALJE     PCT   VALJE     PCT   VALJE     PCT   VALJE     PCT
0.004   0.042   0.004   0.084   0.005   0.127   0.005   0.169   0.005   0.212   0.005   0.254   0.005   0.297   0.005   0.339
0.005   0.382   0.005   0.424   0.005   0.467   0.005   0.509   0.005   0.552   0.005   0.594   0.005   0.637   0.005   0.679
0.005   0.722   0.005   0.764   0.005   0.807   0.005   0.849   0.005   0.892   0.005   0.934   0.005   0.977   0.005   1.019
0.005   1.062   0.005   1.104   0.006   1.146   0.006   1.189   0.006   1.231   0.006   1.274   0.006   1.316   0.006   1.359
0.006   1.401   0.006   1.444   0.006   1.486   0.006   1.529   0.006   1.571   0.006   1.614   0.006   1.656   0.006   1.699
0.006   1.741   0.006   1.784   0.006   1.826   0.006   1.869   0.006   1.911   0.006   1.954   0.006   1.996   0.006   2.039
0.006   2.081   0.006   2.124   0.006   2.166   0.006   2.209   0.006   2.251   0.006   2.293   0.006   2.336   0.006   2.378
0.006   2.421   0.006   2.463   0.006   2.506   0.006   2.548   0.006   2.591   0.006   2.633   0.006   2.676   0.006   2.718
0.006   2.761   0.006   2.803   0.006   2.846   0.006   2.888   0.006   2.931   0.006   2.973   0.006   3.016   0.006   3.058
0.006   3.101   0.006   3.143   0.007   3.186   0.007   3.228   0.007   3.271   0.007   3.313   0.007   3.355   0.007   3.398
0.007   3.440   0.007   3.483   0.007   3.525   0.007   3.568   0.007   3.610   0.007   3.653   0.007   3.695   0.007   3.738
0.007   3.780   0.007   3.823   0.007   3.865   0.007   3.908   0.007   3.950   0.007   3.993   0.007   4.035   0.007   4.078
0.007   4.120   0.007   4.163   0.007   4.205   0.007   4.248   0.007   4.290   0.007   4.333   0.007   4.375   0.007   4.418
0.007   4.460   0.007   4.502   0.007   4.545   0.007   4.587   0.007   4.630   0.007   4.672   0.007   4.715   0.007   4.757
0.007   4.800   0.008   4.842   0.008   4.885   0.008   4.927   0.008   4.970   0.008   5.012   0.008   5.055   0.008   5.097
0.008   5.140   0.008   5.182   0.008   5.225   0.008   5.267   0.008   5.310   0.008   5.352   0.008   5.395   0.008   5.437
0.008   5.480   0.008   5.522   0.008   5.564   0.008   5.607   0.008   5.649   0.008   5.692   0.008   5.734   0.008   5.777
0.008   5.819   0.008   5.862   0.008   5.904   0.008   5.947   0.008   5.989   0.008   6.032   0.008   6.074   0.009   6.117
0.009   6.159   0.009   6.202   0.009   6.244   0.010   6.287   0.010   6.329   0.010   6.372   0.010   6.414   0.010   6.457
0.010   6.499   0.010   6.542   0.010   6.584   0.010   6.627   0.010   6.669   0.010   6.711   0.010   6.754   0.010   6.796
0.010   6.839   0.010   6.881   0.010   6.924   0.010   6.966   0.010   7.009   0.010   7.051   0.010   7.094   0.010   7.136
0.010   7.179   0.010   7.221   0.010   7.264   0.010   7.306   0.010   7.349   0.010   7.391   0.010   7.434   0.010   7.476
0.010   7.519   0.010   7.561   0.010   7.604   0.010   7.646   0.010   7.689   0.010   7.731   0.010   7.774   0.010   7.816
0.010   7.858   0.010   7.901   0.010   7.943   0.010   7.986   0.010   8.028   0.010   8.071   0.010   8.113   0.010   8.156
0.010   8.198   0.010   8.241   0.010   8.283   0.010   8.326   0.010   8.368   0.010   8.411   0.010   8.453   0.010   8.496
0.010   8.538   0.010   8.581   0.010   8.623   0.010   8.666   0.010   8.708   0.010   8.751   0.010   8.793   0.010   8.835
0.010   8.878   0.010   8.920   0.010   8.963   0.010   9.005   0.010   9.048   0.010   9.090   0.010   9.133   0.010   9.175
0.010   9.218   0.010   9.260   0.010   9.303   0.010   9.345   0.010   9.388   0.010   9.430   0.010   9.473   0.010   9.515
0.010   9.558   0.010   9.600   0.010   9.643   0.010   9.685   0.010   9.728   0.010   9.770   0.010   9.813   0.010   9.855
0.010   9.898   0.010   9.940   0.010   9.983   0.010  10.025   0.010  10.067   0.010  10.110   0.010  10.152   0.010  10.195
0.010  10.237   0.010  10.280   0.010  10.322   0.010  10.365   0.010  10.407   0.010  10.450   0.010  10.492   0.010  10.535
0.010  10.577   0.010  10.620   0.010  10.662   0.010  10.705   0.010  10.747   0.010  10.790   0.010  10.832   0.010  10.875
0.010  10.917   0.010  10.960   0.010  11.002   0.010  11.045   0.010  11.087   0.010  11.129   0.010  11.172   0.010  11.214
0.010  11.257   0.010  11.299   0.010  11.342   0.010  11.384   0.010  11.427   0.010  11.469   0.010  11.512   0.010  11.554
0.010  11.597   0.010  11.639   0.010  11.682   0.010  11.724   0.010  11.767   0.010  11.809   0.010  11.852   0.010  11.894
0.010  11.937   0.010  11.979   0.010  12.022   0.010  12.064   0.010  12.107   0.010  12.149   0.010  12.192   0.010  12.234
0.010  12.276   0.010  12.319   0.010  12.361   0.010  12.404   0.010  12.446   0.010  12.489   0.010  12.531   0.010  12.574
0.010  12.616   0.010  12.659   0.010  12.701   0.010  12.744   0.010  12.786   0.010  12.829   0.010  12.871   0.010  12.914
0.010  12.956   0.010  12.999   0.010  13.041   0.010  13.084   0.010  13.126   0.010  13.169   0.010  13.211   0.010  13.254
0.010  13.296   0.010  13.338   0.010  13.381   0.010  13.423   0.010  13.466   0.010  13.508   0.010  13.551   0.010  13.593
0.010  13.636   0.010  13.678   0.010  13.721   0.010  13.763   0.010  13.806   0.010  13.848   0.010  13.891   0.010  13.933
0.010  13.976   0.010  14.018   0.010  14.061   0.010  14.103   0.010  14.146   0.010  14.188   0.010  14.231   0.010  14.273
0.010  14.316   0.010  14.358   0.010  14.401   0.010  14.443   0.010  14.485   0.010  14.528   0.010  14.570   0.010  14.613
0.010  14.655   0.010  14.698   0.010  14.740   0.010  14.783   0.010  14.825   0.010  14.868   0.010  14.910   0.010  14.953
0.010  14.995   0.010  15.038   0.010  15.080   0.010  15.123   0.010  15.165   0.010  15.208   0.010  15.250   0.010  15.293
0.010  15.335   0.010  15.378   0.010  15.420   0.010  15.463   0.010  15.505   0.010  15.548   0.010  15.590   0.010  15.632
0.010  15.675   0.010  15.717   0.010  15.760   0.010  15.802   0.010  15.845   0.010  15.887   0.010  15.930   0.010  15.972
0.010  16.015   0.010  16.057   0.010  16.100   0.010  16.142   0.010  16.185   0.010  16.227   0.010  16.270   0.010  16.312
0.010  16.355   0.010  16.397   0.010  16.440   0.010  16.482   0.010  16.525   0.010  16.567   0.010  16.610   0.010  16.652
0.010  16.694   0.010  16.737   0.010  16.779   0.010  16.822   0.010  16.864   0.010  16.907   0.010  16.949   0.010  16.992
0.010  17.034   0.010  17.077   0.010  17.119   0.010  17.162   0.010  17.204   0.010  17.247   0.010  17.289   0.010  17.332
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0.010  17.374   0.010  17.417   0.010  17.459   0.010  17.502   0.010  17.544   0.010  17.587   0.010  17.629   0.010  17.672
0.010  17.714   0.010  17.757   0.010  17.799   0.010  17.841   0.010  17.884   0.010  17.926   0.010  17.969   0.010  18.011
0.010  18.054   0.010  18.096   0.010  18.139   0.010  18.181   0.010  18.224   0.010  18.266   0.010  18.309   0.010  18.351
0.010  18.394   0.010  18.436   0.010  18.479   0.010  18.521   0.010  18.564   0.010  18.606   0.010  18.649   0.010  18.691
0.010  18.734   0.010  18.776   0.010  18.819   0.010  18.861   0.010  18.903   0.010  18.946   0.010  18.988   0.010  19.031
0.010  19.073   0.010  19.116   0.010  19.159   0.010  19.201   0.010  19.243   0.010  19.286   0.010  19.328   0.010  19.371
0.010  19.413   0.010  19.456   0.010  19.498   0.010  19.541   0.010  19.583   0.010  19.626   0.010  19.668   0.010  19.711
0.010  19.753   0.010  19.796   0.010  19.838   0.010  19.881   0.010  19.923   0.010  19.966   0.010  20.008   0.010  20.050
0.010  20.093   0.010  20.135   0.010  20.178   0.010  20.220   0.010  20.262   0.010  20.305   0.010  20.348   0.010  20.390
0.010  20.433   0.010  20.475   0.010  20.518   0.010  20.560   0.010  20.603   0.010  20.645   0.010  20.688   0.010  20.730
0.010  20.773   0.010  20.815   0.010  20.858   0.010  20.900   0.010  20.943   0.010  20.985   0.010  21.028   0.010  21.070
0.010  21.113   0.010  21.155   0.010  21.197   0.010  21.240   0.010  21.282   0.010  21.325   0.010  21.367   0.010  21.410
0.010  21.452   0.010  21.495   0.010  21.537   0.010  21.580   0.010  21.622   0.010  21.665   0.010  21.707   0.010  21.750
0.010  21.792   0.010  21.835   0.010  21.877   0.010  21.920   0.010  21.962   0.010  22.005   0.010  22.047   0.010  22.090
0.010  22.132   0.010  22.175   0.010  22.217   0.010  22.259   0.010  22.302   0.010  22.344   0.010  22.387   0.010  22.429
0.010  22.472   0.010  22.514   0.010  22.557   0.010  22.599   0.010  22.642   0.010  22.684   0.010  22.727   0.010  22.769
0.010  22.812   0.010  22.854   0.010  22.897   0.010  22.939   0.010  22.982   0.010  23.024   0.010  23.067   0.010  23.109
0.010  23.152   0.010  23.194   0.010  23.237   0.010  23.279   0.010  23.322   0.010  23.364   0.010  23.406   0.010  23.449
0.010  23.491   0.010  23.534   0.010  23.576   0.010  23.619   0.010  23.661   0.010  23.704   0.010  23.746   0.010  23.789
0.010  23.831   0.010  23.874   0.010  23.916   0.010  23.959   0.010  24.001   0.010  24.044   0.010  24.086   0.010  24.129
0.010  24.171   0.010  24.214   0.010  24.256   0.010  24.299   0.010  24.341   0.010  24.384   0.010  24.426   0.010  24.469
0.010  24.511   0.010  24.553   0.010  24.596   0.010  24.638   0.010  24.681   0.010  24.723   0.010  24.766   0.010  24.808
0.010  24.851   0.010  24.893   0.010  24.936   0.010  24.978   0.010  25.021   0.010  25.063   0.010  25.106   0.010  25.148
0.010  25.191   0.010  25.233   0.010  25.276   0.010  25.318   0.010  25.361   0.010  25.403   0.010  25.446   0.010  25.488
0.010  25.531   0.010  25.573   0.010  25.615   0.010  25.658   0.010  25.700   0.010  25.743   0.010  25.785   0.010  25.828
0.010  25.870   0.010  25.913   0.010  25.955   0.010  25.998   0.010  26.040   0.010  26.083   0.010  26.125   0.010  26.168
0.010  26.210   0.010  26.253   0.010  26.295   0.010  26.338   0.010  26.380   0.010  26.423   0.010  26.465   0.010  26.508
0.010  26.550   0.010  26.593   0.010  26.635   0.010  26.677   0.010  26.720   0.010  26.762   0.010  26.805   0.010  26.847
0.010  26.890   0.010  26.932   0.010  26.975   0.010  27.017   0.010  27.060   0.010  27.102   0.010  27.145   0.010  27.187
0.010  27.230   0.010  27.272   0.010  27.315   0.010  27.357   0.010  27.400   0.010  27.442   0.010  27.485   0.010  27.527
0.010  27.570   0.010  27.612   0.010  27.655   0.010  27.697   0.010  27.740   0.010  27.782   0.010  27.824   0.010  27.867
0.010  27.909   0.010  27.952   0.010  27.994   0.010  28.037   0.010  28.079   0.010  28.122   0.010  28.164   0.010  28.207
0.010  28.249   0.010  28.292   0.010  28.334   0.010  28.377   0.010  28.419   0.010  28.462   0.010  28.504   0.010  28.547
0.010  28.589   0.010  28.632   0.010  28.674   0.010  28.717   0.010  28.759   0.010  28.802   0.010  28.844   0.010  28.887
0.010  28.929   0.010  28.971   0.010  29.014   0.010  29.056   0.010  29.099   0.010  29.141   0.010  29.184   0.010  29.226
0.010  29.269   0.010  29.311   0.010  29.354   0.010  29.396   0.010  29.439   0.010  29.481   0.010  29.524   0.010  29.566
0.010  29.609   0.010  29.651   0.010  29.694   0.010  29.736   0.010  29.779   0.010  29.821   0.010  29.864   0.010  29.906
0.010  29.949   0.010  29.991   0.010  30.033   0.010  30.076   0.010  30.118   0.010  30.161   0.010  30.203   0.010  30.246
0.010  30.288   0.010  30.331   0.010  30.373   0.010  30.416   0.010  30.458   0.010  30.501   0.010  30.543   0.010  30.586
0.010  30.628   0.010  30.671   0.010  30.713   0.010  30.756   0.010  30.798   0.010  30.841   0.010  30.883   0.010  30.926
0.010  30.968   0.010  31.011   0.010  31.053   0.010  31.096   0.010  31.138   0.010  31.180   0.010  31.223   0.010  31.265
0.010  31.308   0.010  31.350   0.010  31.393   0.010  31.435   0.010  31.478   0.010  31.520   0.010  31.563   0.010  31.605
0.010  31.648   0.010  31.690   0.010  31.733   0.010  31.775   0.010  31.818   0.010  31.860   0.010  31.903   0.010  31.945
0.010  31.988   0.010  32.030   0.010  32.073   0.010  32.115   0.010  32.158   0.010  32.200   0.010  32.242   0.010  32.285
0.010  32.327   0.010  32.370   0.010  32.412   0.010  32.455   0.010  32.497   0.010  32.540   0.010  32.582   0.010  32.625
0.010  32.667   0.010  32.710   0.010  32.752   0.010  32.795   0.010  32.837   0.010  32.880   0.010  32.922   0.010  32.965
0.010  33.007   0.010  33.050   0.010  33.092   0.010  33.135   0.010  33.177   0.010  33.220   0.010  33.262   0.010  33.305
0.010  33.347   0.010  33.389   0.010  33.432   0.010  33.474   0.010  33.517   0.010  33.559   0.010  33.602   0.010  33.644
0.010  33.687   0.010  33.729   0.010  33.772   0.010  33.814   0.010  33.857   0.010  33.899   0.010  33.942   0.010  33.984
0.010  34.027   0.010  34.069   0.010  34.112   0.010  34.154   0.010  34.197   0.010  34.239   0.010  34.282   0.010  34.324
0.010  34.367   0.010  34.409   0.010  34.452   0.010  34.494   0.010  34.536   0.010  34.579   0.010  34.621   0.010  34.664
0.010  34.706   0.010  34.749   0.010  34.791   0.010  34.834   0.010  34.876   0.010  34.919   0.010  34.961   0.010  35.004
0.010  35.046   0.010  35.089   0.010  35.131   0.010  35.174   0.010  35.216   0.010  35.259   0.010  35.301   0.010  35.344
0.010  35.386   0.010  35.429   0.010  35.471   0.010  35.514   0.010  35.556   0.010  35.598   0.010  35.641   0.010  35.683
0.010  35.726   0.010  35.768   0.010  35.811   0.010  35.853   0.010  35.896   0.010  35.938   0.010  35.981   0.010  36.023
0.010  36.066   0.010  36.108   0.010  36.151   0.010  36.193   0.010  36.236   0.010  36.278   0.010  36.321   0.010  36.363
0.010  36.406   0.010  36.448   0.010  36.491   0.010  36.533   0.010  36.576   0.010  36.618   0.010  36.661   0.010  36.703
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0.010  36.745   0.010  36.788   0.010  36.830   0.010  36.873   0.010  36.915   0.010  36.958   0.010  37.000   0.010  37.043
0.010  37.085   0.010  37.128   0.010  37.170   0.010  37.213   0.010  37.255   0.010  37.298   0.010  37.340   0.010  37.383
0.010  37.425   0.010  37.468   0.010  37.510   0.010  37.553   0.010  37.595   0.010  37.638   0.010  37.680   0.010  37.723
0.010  37.765   0.010  37.807   0.010  37.850   0.010  37.892   0.010  37.935   0.010  37.977   0.010  38.020   0.010  38.062
0.010  38.105   0.010  38.147   0.010  38.190   0.011  38.232   0.011  38.275   0.011  38.317   0.011  38.360   0.011  38.402
0.011  38.445   0.011  38.487   0.011  38.530   0.011  38.572   0.011  38.615   0.011  38.657   0.011  38.700   0.011  38.742
0.011  38.785   0.011  38.827   0.011  38.870   0.011  38.912   0.011  38.954   0.011  38.997   0.011  39.039   0.011  39.082
0.011  39.124   0.011  39.167   0.011  39.209   0.012  39.252   0.012  39.294   0.012  39.337   0.012  39.379   0.012  39.422
0.012  39.464   0.012  39.507   0.012  39.549   0.012  39.592   0.012  39.634   0.012  39.677   0.012  39.719   0.012  39.762
0.012  39.804   0.012  39.847   0.012  39.889   0.012  39.932   0.012  39.974   0.012  40.016   0.012  40.059   0.012  40.101
0.012  40.144   0.012  40.186   0.012  40.229   0.012  40.271   0.012  40.314   0.012  40.356   0.012  40.399   0.012  40.441
0.012  40.484   0.012  40.526   0.012  40.569   0.012  40.611   0.012  40.654   0.012  40.696   0.012  40.739   0.012  40.781
0.012  40.824   0.012  40.866   0.012  40.909   0.012  40.951   0.012  40.994   0.012  41.036   0.012  41.079   0.012  41.121
0.013  41.163   0.013  41.206   0.013  41.248   0.013  41.291   0.013  41.333   0.013  41.376   0.013  41.418   0.013  41.461
0.013  41.503   0.013  41.546   0.013  41.588   0.013  41.631   0.013  41.673   0.013  41.716   0.013  41.758   0.013  41.801
0.013  41.843   0.013  41.886   0.013  41.928   0.013  41.971   0.013  42.013   0.013  42.056   0.013  42.098   0.013  42.141
0.013  42.183   0.013  42.226   0.013  42.268   0.013  42.310   0.013  42.353   0.013  42.395   0.013  42.438   0.014  42.480
0.014  42.523   0.014  42.565   0.014  42.608   0.014  42.650   0.014  42.693   0.014  42.735   0.014  42.778   0.014  42.820
0.014  42.863   0.014  42.905   0.014  42.948   0.014  42.990   0.014  43.033   0.014  43.075   0.014  43.118   0.014  43.160
0.014  43.203   0.014  43.245   0.014  43.288   0.014  43.330   0.015  43.372   0.015  43.415   0.015  43.457   0.015  43.500
0.015  43.542   0.015  43.585   0.015  43.627   0.015  43.670   0.015  43.712   0.015  43.755   0.015  43.797   0.015  43.840
0.015  43.882   0.015  43.925   0.015  43.967   0.015  44.010   0.015  44.052   0.015  44.095   0.015  44.137   0.015  44.180
0.015  44.222   0.015  44.265   0.015  44.307   0.015  44.350   0.015  44.392   0.015  44.435   0.015  44.477   0.015  44.519
0.015  44.562   0.015  44.604   0.015  44.647   0.015  44.689   0.015  44.732   0.015  44.774   0.015  44.817   0.015  44.859
0.015  44.902   0.015  44.944   0.015  44.987   0.015  45.029   0.015  45.072   0.015  45.114   0.015  45.157   0.015  45.199
0.015  45.242   0.015  45.284   0.015  45.327   0.015  45.369   0.015  45.412   0.015  45.454   0.015  45.497   0.015  45.539
0.015  45.581   0.015  45.624   0.015  45.666   0.015  45.709   0.015  45.751   0.015  45.794   0.015  45.836   0.015  45.879
0.015  45.921   0.015  45.964   0.015  46.006   0.015  46.049   0.015  46.091   0.015  46.134   0.015  46.176   0.015  46.219
0.015  46.261   0.015  46.304   0.015  46.346   0.015  46.389   0.016  46.431   0.016  46.474   0.015  46.516   0.016  46.559
0.016  46.601   0.016  46.644   0.016  46.686   0.016  46.728   0.016  46.771   0.016  46.813   0.016  46.856   0.016  46.899
0.016  46.941   0.016  46.983   0.016  47.026   0.016  47.068   0.016  47.111   0.016  47.153   0.016  47.196   0.016  47.239
0.016  47.281   0.016  47.323   0.016  47.366   0.016  47.408   0.016  47.451   0.016  47.493   0.016  47.536   0.017  47.579
0.017  47.621   0.017  47.663   0.017  47.706   0.017  47.748   0.017  47.791   0.017  47.833   0.017  47.875   0.017  47.919
0.017  47.960   0.017  48.003   0.017  48.045   0.017  48.088   0.017  48.130   0.017  48.173   0.017  48.215   0.017  48.259
0.017  48.300   0.018  48.343   0.018  48.385   0.018  48.428   0.018  48.470   0.018  48.513   0.018  48.555   0.018  48.599
0.018  48.640   0.018  48.683   0.018  48.725   0.018  48.768   0.018  48.810   0.018  48.853   0.018  48.895   0.018  48.937
0.018  48.980   0.018  49.022   0.019  49.065   0.018  49.107   0.018  49.150   0.018  49.192   0.019  49.235   0.019  49.277
0.019  49.320   0.019  49.362   0.020  49.405   0.020  49.447   0.020  49.490   0.020  49.532   0.020  49.575   0.020  49.617
0.020  49.660   0.020  49.702   0.020  49.745   0.020  49.787   0.020  49.830   0.020  49.872   0.020  49.915   0.020  49.957
0.020  50.000   0.020  50.042   0.020  50.084   0.020  50.127   0.020  50.169   0.020  50.212   0.020  50.254   0.020  50.297
0.020  50.339   0.020  50.382   0.020  50.424   0.020  50.467   0.020  50.509   0.020  50.552   0.020  50.594   0.020  50.637
0.020  50.679   0.020  50.722   0.020  50.764   0.020  50.807   0.020  50.849   0.020  50.892   0.020  50.934   0.020  50.977
0.020  51.019   0.020  51.062   0.020  51.104   0.020  51.146   0.020  51.189   0.020  51.231   0.020  51.274   0.020  51.316
0.020  51.359   0.020  51.401   0.020  51.444   0.020  51.486   0.020  51.529   0.020  51.571   0.020  51.614   0.020  51.656
0.020  51.699   0.020  51.741   0.020  51.784   0.020  51.826   0.020  51.869   0.020  51.911   0.020  51.954   0.020  51.996
0.020  52.039   0.020  52.081   0.020  52.124   0.020  52.166   0.020  52.209   0.020  52.251   0.020  52.293   0.020  52.336
0.020  52.379   0.020  52.421   0.020  52.463   0.020  52.506   0.020  52.548   0.020  52.591   0.020  52.633   0.020  52.676
0.020  52.719   0.020  52.761   0.020  52.803   0.020  52.846   0.020  52.888   0.020  52.931   0.020  52.973   0.020  53.016
0.020  53.058   0.020  53.101   0.020  53.143   0.020  53.186   0.020  53.228   0.020  53.271   0.020  53.313   0.020  53.355
0.020  53.398   0.020  53.440   0.020  53.483   0.020  53.525   0.020  53.568   0.020  53.610   0.020  53.653   0.020  53.695
0.020  53.738   0.020  53.780   0.020  53.823   0.020  53.865   0.020  53.908   0.020  53.950   0.020  53.993   0.020  54.035
0.020  54.078   0.020  54.120   0.020  54.163   0.020  54.205   0.020  54.248   0.020  54.290   0.020  54.333   0.020  54.375
0.020  54.418   0.020  54.460   0.020  54.502   0.020  54.545   0.020  54.587   0.020  54.630   0.020  54.672   0.020  54.715
0.020  54.757   0.020  54.800   0.020  54.842   0.020  54.885   0.020  54.927   0.020  54.970   0.020  55.012   0.020  55.055
0.020  55.097   0.020  55.140   0.020  55.182   0.020  55.225   0.020  55.267   0.020  55.310   0.020  55.352   0.020  55.394
0.020  55.437   0.020  55.480   0.020  55.522   0.020  55.565   0.020  55.607   0.020  55.649   0.020  55.692   0.020  55.734
0.020  55.777   0.020  55.819   0.020  55.862   0.020  55.904   0.020  55.947   0.020  55.989   0.020  56.032   0.020  56.074
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0.020  56.117   0.020  56.159   0.020  56.202   0.020  56.244   0.020  56.287   0.020  56.329   0.020  56.372   0.020  56.414
0.020  56.457   0.020  56.499   0.020  56.542   0.020  56.584   0.020  56.627   0.020  56.669   0.020  56.711   0.020  56.754
0.020  56.796   0.020  56.839   0.020  56.881   0.020  56.924   0.020  56.966   0.020  57.009   0.020  57.051   0.020  57.094
0.020  57.136   0.020  57.179   0.020  57.221   0.020  57.264   0.020  57.306   0.020  57.349   0.020  57.391   0.020  57.434
0.020  57.476   0.020  57.519   0.020  57.561   0.020  57.604   0.020  57.646   0.020  57.689   0.020  57.731   0.020  57.774
0.020  57.816   0.020  57.858   0.020  57.901   0.020  57.943   0.020  57.986   0.020  58.028   0.020  58.071   0.020  58.113
0.020  58.156   0.020  58.198   0.020  58.241   0.020  58.283   0.020  58.326   0.021  58.368   0.021  58.411   0.021  58.453
0.021  58.496   0.021  58.538   0.021  58.581   0.021  58.623   0.021  58.666   0.021  58.708   0.021  58.751   0.021  58.793
0.021  58.836   0.021  58.878   0.021  58.920   0.022  58.963   0.022  59.005   0.022  59.048   0.022  59.090   0.022  59.133
0.022  59.175   0.022  59.218   0.022  59.260   0.022  59.303   0.022  59.345   0.022  59.388   0.022  59.430   0.022  59.473
0.022  59.515   0.022  59.558   0.022  59.600   0.022  59.643   0.022  59.685   0.022  59.728   0.022  59.770   0.022  59.813
0.022  59.855   0.022  59.898   0.022  59.940   0.023  59.983   0.023  60.025   0.023  60.067   0.023  60.110   0.023  60.152
0.023  60.195   0.023  60.237   0.023  60.280   0.023  60.322   0.023  60.365   0.023  60.407   0.023  60.450   0.023  60.492
0.023  60.535   0.023  60.577   0.023  60.620   0.023  60.662   0.023  60.705   0.023  60.747   0.023  60.790   0.023  60.832
0.023  60.875   0.023  60.917   0.023  60.960   0.023  61.002   0.023  61.045   0.024  61.087   0.024  61.129   0.024  61.172
0.024  61.214   0.024  61.257   0.024  61.299   0.024  61.342   0.024  61.384   0.024  61.427   0.024  61.469   0.024  61.512
0.024  61.554   0.024  61.597   0.024  61.639   0.025  61.682   0.025  61.724   0.025  61.767   0.025  61.809   0.025  61.852
0.025  61.894   0.025  61.937   0.025  61.979   0.025  62.022   0.025  62.064   0.025  62.107   0.025  62.149   0.025  62.192
0.025  62.234   0.025  62.276   0.025  62.319   0.025  62.361   0.025  62.404   0.025  62.446   0.025  62.489   0.025  62.531
0.025  62.574   0.025  62.616   0.025  62.659   0.025  62.701   0.025  62.744   0.025  62.786   0.025  62.829   0.025  62.871
0.025  62.914   0.025  62.956   0.025  62.999   0.025  63.041   0.025  63.084   0.025  63.126   0.025  63.169   0.025  63.211
0.025  63.254   0.025  63.296   0.025  63.339   0.025  63.381   0.025  63.423   0.025  63.466   0.025  63.508   0.025  63.551
0.025  63.593   0.025  63.636   0.025  63.678   0.025  63.721   0.025  63.763   0.025  63.806   0.025  63.848   0.025  63.891
0.025  63.933   0.026  63.976   0.026  64.018   0.026  64.061   0.026  64.103   0.026  64.146   0.026  64.188   0.026  64.231
0.026  64.273   0.026  64.316   0.026  64.358   0.026  64.401   0.026  64.443   0.025  64.485   0.025  64.528   0.026  64.570
0.026  64.613   0.026  64.655   0.026  64.698   0.026  64.740   0.026  64.783   0.026  64.825   0.025  64.868   0.026  64.910
0.026  64.953   0.026  64.995   0.026  65.038   0.027  65.080   0.027  65.123   0.027  65.165   0.027  65.208   0.027  65.250
0.027  65.293   0.027  65.335   0.027  65.378   0.027  65.420   0.027  65.463   0.027  65.505   0.027  65.548   0.027  65.590
0.027  65.632   0.027  65.675   0.027  65.717   0.028  65.760   0.028  65.802   0.028  65.845   0.028  65.887   0.028  65.930
0.028  65.972   0.028  66.015   0.028  66.057   0.029  66.100   0.028  66.142   0.028  66.185   0.028  66.227   0.028  66.270
0.028  66.312   0.028  66.355   0.029  66.397   0.029  66.440   0.029  66.482   0.029  66.525   0.029  66.567   0.029  66.610
0.029  66.652   0.030  66.694   0.030  66.737   0.030  66.779   0.030  66.822   0.030  66.864   0.030  66.907   0.030  66.949
0.030  66.992   0.030  67.034   0.030  67.077   0.030  67.119   0.030  67.162   0.030  67.204   0.030  67.247   0.030  67.289
0.030  67.332   0.030  67.374   0.030  67.417   0.030  67.459   0.030  67.502   0.030  67.544   0.030  67.587   0.030  67.629
0.030  67.672   0.030  67.714   0.030  67.757   0.030  67.799   0.030  67.841   0.030  67.884   0.030  67.926   0.030  67.969
0.030  68.011   0.030  68.054   0.030  68.096   0.030  68.139   0.030  68.181   0.030  68.224   0.030  68.266   0.030  68.309
0.030  68.351   0.030  68.394   0.030  68.436   0.030  68.479   0.030  68.521   0.030  68.564   0.030  68.606   0.030  68.649
0.030  68.691   0.030  68.734   0.030  68.776   0.030  68.819   0.030  68.861   0.030  68.904   0.030  68.946   0.030  68.988
0.030  69.031   0.030  69.073   0.030  69.116   0.030  69.158   0.030  69.201   0.030  69.243   0.030  69.286   0.030  69.328
0.030  69.371   0.030  69.413   0.030  69.456   0.030  69.498   0.030  69.541   0.030  69.583   0.030  69.626   0.030  69.668
0.030  69.711   0.030  69.753   0.030  69.796   0.030  69.838   0.030  69.881   0.030  69.923   0.030  69.966   0.030  70.008
0.030  70.050   0.030  70.093   0.030  70.135   0.030  70.178   0.030  70.220   0.030  70.263   0.030  70.305   0.030  70.348
0.030  70.390   0.030  70.433   0.030  70.475   0.030  70.518   0.030  70.560   0.030  70.603   0.030  70.645   0.030  70.688
0.030  70.730   0.030  70.773   0.030  70.815   0.030  70.858   0.030  70.900   0.030  70.943   0.030  70.985   0.031  71.028
0.031  71.070   0.031  71.113   0.031  71.155   0.031  71.197   0.031  71.240   0.031  71.282   0.031  71.325   0.032  71.367
0.032  71.410   0.032  71.452   0.032  71.495   0.032  71.537   0.032  71.580   0.032  71.622   0.032  71.665   0.032  71.707
0.032  71.750   0.032  71.792   0.032  71.835   0.032  71.877   0.032  71.920   0.032  71.962   0.032  72.005   0.032  72.047
0.032  72.090   0.033  72.132   0.033  72.175   0.033  72.217   0.033  72.259   0.033  72.302   0.033  72.344   0.033  72.387
0.033  72.429   0.033  72.472   0.033  72.514   0.033  72.557   0.033  72.599   0.033  72.642   0.033  72.684   0.033  72.727
0.033  72.769   0.033  72.812   0.033  72.854   0.033  72.897   0.034  72.939   0.034  72.982   0.034  73.024   0.034  73.067
0.034  73.109   0.034  73.152   0.034  73.194   0.034  73.237   0.034  73.279   0.035  73.322   0.035  73.364   0.035  73.406
0.035  73.449   0.035  73.491   0.035  73.534   0.035  73.576   0.035  73.619   0.035  73.661   0.035  73.704   0.035  73.746
0.035  73.789   0.035  73.831   0.035  73.874   0.035  73.916   0.035  73.959   0.035  74.001   0.035  74.044   0.035  74.086
0.035  74.129   0.035  74.171   0.035  74.214   0.035  74.256   0.035  74.299   0.036  74.341   0.036  74.384   0.036  74.[illegible]
0.036  74.468   0.036  74.511   0.036  74.553   0.036  74.596   0.036  74.638   0.036  74.681   0.036  74.723   0.036  74.[illegible]
0.036  74.808   0.036  74.851   0.037  74.893   0.037  74.936   0.037  74.978   0.037  75.021   0.037  75.063   0.037  75.105
0.037  75.148   0.037  75.191   0.038  75.233   0.038  75.276   0.038  75.318   0.038  75.361   0.038  75.403   0.038  75.445
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0.038  75.488   0.039  75.531   0.039  75.573   0.039  75.615   0.039  75.658   0.040  75.700   0.040  75.743   0.040  75.785
0.040  75.828   0.040  75.870   0.040  75.913   0.040  75.955   0.040  75.998   0.040  76.040   0.040  76.083   0.040  76.125
0.040  76.168   0.040  76.210   0.040  76.253   0.040  76.295   0.040  76.338   0.040  76.380   0.040  76.423   0.040  76.465
0.040  76.508   0.040  76.550   0.040  76.593   0.040  76.635   0.040  76.678   0.040  76.720   0.040  76.762   0.040  76.805
0.040  76.847   0.040  76.890   0.040  76.932   0.040  76.975   0.040  77.017   0.040  77.060   0.040  77.102   0.040  77.145
0.040  77.187   0.040  77.230   0.040  77.272   0.040  77.315   0.040  77.357   0.040  77.400   0.040  77.442   0.040  77.485
0.040  77.527   0.040  77.570   0.040  77.612   0.040  77.655   0.040  77.697   0.040  77.740   0.040  77.782   0.040  77.824
0.040  77.867   0.040  77.909   0.040  77.952   0.040  77.994   0.040  78.037   0.040  78.079   0.040  78.122   0.040  78.164
0.040  78.207   0.041  78.249   0.041  78.292   0.041  78.334   0.042  78.377   0.042  78.419   0.042  78.462   0.042  78.504
0.042  78.547   0.042  78.589   0.042  78.632   0.042  78.674   0.042  78.717   0.043  78.759   0.043  78.802   0.043  78.844
0.043  78.887   0.044  78.929   0.044  78.971   0.044  79.014   0.044  79.056   0.044  79.099   0.044  79.141   0.044  79.184
0.044  79.226   0.044  79.269   0.045  79.311   0.045  79.354   0.045  79.396   0.045  79.439   0.045  79.481   0.045  79.524
0.045  79.566   0.045  79.609   0.045  79.651   0.045  79.694   0.045  79.736   0.045  79.779   0.045  79.821   0.045  79.864
0.045  79.906   0.045  79.949   0.045  79.991   0.045  80.033   0.045  80.076   0.045  80.118   0.045  80.161   0.045  80.203
0.045  80.246   0.045  80.288   0.045  80.331   0.045  80.373   0.045  80.416   0.046  80.458   0.046  80.501   0.046  80.543
0.046  80.586   0.046  80.628   0.046  80.671   0.047  80.713   0.047  80.756   0.047  80.798   0.047  80.841   0.047  80.883
0.047  80.926   0.048  80.968   0.048  81.011   0.048  81.053   0.048  81.096   0.048  81.138   0.049  81.180   0.049  81.223
0.049  81.265   0.049  81.308   0.050  81.350   0.050  81.393   0.050  81.435   0.050  81.478   0.050  81.520   0.050  81.563
0.050  81.605   0.050  81.648   0.050  81.690   0.050  81.733   0.050  81.775   0.050  81.818   0.050  81.860   0.050  81.903
0.050  81.945   0.050  81.988   0.050  82.030   0.050  82.073   0.050  82.115   0.050  82.158   0.050  82.200   0.050  82.242
0.050  82.285   0.050  82.327   0.050  82.370   0.050  82.412   0.050  82.455   0.050  82.497   0.050  82.540   0.050  82.582
0.050  82.625   0.050  82.667   0.050  82.710   0.050  82.752   0.050  82.795   0.050  82.837   0.050  82.880   0.050  82.922
0.050  82.965   0.051  83.007   0.051  83.050   0.051  83.092   0.051  83.135   0.051  83.177   0.052  83.220   0.052  83.262
0.052  83.305   0.052  83.347   0.052  83.389   0.052  83.432   0.052  83.474   0.053  83.517   0.053  83.559   0.053  83.602
0.053  83.644   0.053  83.687   0.053  83.729   0.053  83.772   0.053  83.814   0.053  83.857   0.054  83.899   0.054  83.942
0.054  83.984   0.054  84.027   0.054  84.069   0.054  84.112   0.054  84.154   0.054  84.197   0.054  84.239   0.055  84.282
0.055  84.324   0.055  84.367   0.055  84.409   0.055  84.452   0.055  84.494   0.055  84.536   0.055  84.579   0.055  84.621
0.055  84.664   0.055  84.706   0.055  84.749   0.056  84.791   0.056  84.834   0.056  84.876   0.056  84.919   0.056  84.961
0.056  85.004   0.056  85.046   0.056  85.089   0.056  85.131   0.056  85.174   0.056  85.216   0.057  85.259   0.057  85.301
0.058  85.344   0.059  85.386   0.060  85.429   0.060  85.471   0.060  85.514   0.060  85.556   0.060  85.598   0.060  85.641
0.060  85.683   0.060  85.726   0.060  85.768   0.060  85.811   0.060  85.853   0.060  85.896   0.060  85.938   0.060  85.981
0.060  86.023   0.060  86.066   0.060  86.108   0.060  86.151   0.060  86.193   0.060  86.235   0.060  86.278   0.060  86.321
0.060  86.363   0.060  86.406   0.060  86.448   0.060  86.491   0.060  86.533   0.060  86.576   0.060  86.618   0.060  86.661
0.060  86.703   0.060  86.746   0.060  86.788   0.060  86.830   0.060  86.873   0.060  86.915   0.061  86.958   0.061  87.000
0.061  87.043   0.062  87.085   0.062  87.128   0.062  87.170   0.063  87.213   0.063  87.255   0.063  87.298   0.063  87.340
0.063  87.383   0.064  87.425   0.065  87.468   0.065  87.510   0.065  87.553   0.065  87.595   0.065  87.638   0.065  87.680
0.065  87.723   0.065  87.765   0.065  87.807   0.065  87.850   0.066  87.892   0.066  87.935   0.067  87.977   0.067  88.020
0.067  88.062   0.067  88.105   0.067  88.147   0.070  88.190   0.070  88.232   0.070  88.275   0.070  88.317   0.070  88.360
0.070  88.402   0.070  88.445   0.070  88.487   0.070  88.530   0.070  88.572   0.070  88.615   0.070  88.657   0.070  88.700
0.070  88.742   0.070  88.785   0.070  88.827   0.070  88.870   0.070  88.912   0.070  88.954   0.070  88.997   0.070  89.039
0.071  89.082   0.071  89.124   0.072  89.167   0.072  89.209   0.073  89.252   0.073  89.294   0.073  89.337   0.073  89.379
0.073  89.422   0.074  89.464   0.074  89.507   0.074  89.549   0.075  89.592   0.075  89.634   0.075  89.677   0.075  89.719
0.076  89.762   0.076  89.804   0.076  89.847   0.076  89.889   0.076  89.932   0.077  89.974   0.077  90.016   0.077  90.059
0.077  90.101   0.080  90.144   0.080  90.186   0.080  90.229   0.080  90.271   0.080  90.314   0.080  90.356   0.080  90.399
0.080  90.441   0.080  90.484   0.080  90.526   0.080  90.569   0.080  90.611   0.080  90.654   0.080  90.696   0.080  90.739
0.080  90.781   0.082  90.824   0.082  90.866   0.082  90.909   0.083  90.951   0.083  90.994   0.084  91.036   0.084  91.079
0.085  91.121   0.085  91.163   0.085  91.206   0.085  91.249   0.085  91.291   0.086  91.333   0.087  91.376   0.087  91.419
0.088  91.461   0.088  91.503   0.090  91.546   0.090  91.588   0.090  91.631   0.090  91.673   0.090  91.716   0.090  91.759
0.090  91.801   0.090  91.843   0.090  91.886   0.090  91.928   0.090  91.971   0.090  92.013   0.090  92.056   0.091  92.098
0.092  92.141   0.092  92.183   0.092  92.226   0.094  92.268   0.095  92.310   0.095  92.353   0.095  92.395   0.095  92.438
0.095  92.480   0.095  92.523   0.095  92.565   0.095  92.608   0.096  92.650   0.096  92.693   0.097  92.735   0.097  92.778
0.100  92.820   0.100  92.863   0.100  92.905   0.100  92.948   0.100  92.990   0.100  93.033   0.100  93.075   0.100  93.118
0.100  93.160   0.100  93.203   0.105  93.245   0.105  93.288   0.105  93.330   0.105  93.372   0.105  93.415   0.106  93.457
0.106  93.500   0.106  93.542   0.106  93.585   0.107  93.627   0.110  93.670   0.110  93.712   0.110  93.755   0.110  93.797
0.110  93.840   0.110  93.882   0.112  93.925   0.112  93.967   0.114  94.010   0.115  94.052   0.115  94.095   0.118  94.137
0.120  94.180   0.120  94.222   0.120  94.265   0.120  94.307   0.120  94.350   0.120  94.392   0.120  94.435   0.120  94.477
0.120  94.519   0.120  94.562   0.120  94.604   0.120  94.647   0.120  94.689   0.120  94.732   0.123  94.774   0.123  94.817
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0.123  94.859   0.125  94.902   0.125  94.944   0.125  94.987   0.126  95.029   0.126  95.072   0.127  95.114   0.128  95.157
0.130  95.199   0.130  95.242   0.130  95.284   0.130  95.327   0.130  95.369   0.130  95.412   0.130  95.454   0.130  95.497
0.130  95.539   0.130  95.582   0.130  95.624   0.130  95.666   0.133  95.709   0.135  95.751   0.135  95.794   0.136  95.836
0.136  95.879   0.137  95.921   0.138  95.964   0.138  96.006   0.140  96.049   0.140  96.091   0.140  96.134   0.140  96.176
0.140  96.219   0.140  96.261   0.140  96.304   0.142  96.346   0.146  96.389   0.147  96.431   0.150  96.474   0.154  96.516
0.155  96.559   0.155  96.601   0.160  96.644   0.160  96.686   0.160  96.728   0.160  96.771   0.160  96.813   0.163  96.856
0.165  96.898   0.167  96.941   0.167  96.983   0.170  97.026   0.170  97.068   0.170  97.111   0.172  97.153   0.176  97.196
0.180  97.238   0.180  97.281   0.183  97.323   0.190  97.366   0.190  97.408   0.190  97.451   0.190  97.493   0.191  97.536
0.195  97.578   0.200  97.621   0.200  97.663   0.200  97.706   0.200  97.748   0.200  97.791   0.200  97.833   0.201  97.875
0.210  97.918   0.210  97.960   0.213  98.003   0.216  98.045   0.216  98.088   0.220  98.130   0.225  98.173   0.230  98.215
0.230  98.258   0.233  98.300   0.235  98.343   0.240  98.385   0.240  98.428   0.260  98.470   0.265  98.513   0.266  98.555
0.270  98.598   0.270  98.640   0.270  98.683   0.272  98.725   0.275  98.768   0.276  98.810   0.290  98.853   0.290  98.895
0.302  98.937   0.320  98.980   0.325  99.022   0.330  99.065   0.341  99.107   0.345  99.150   0.350  99.192   0.350  99.235
0.350  99.277   0.390  99.320   0.390  99.362   0.412  99.405   0.416  99.447   0.420  99.490   0.420  99.532   0.475  99.575
0.480  99.617   0.503  99.660   0.520  99.702   0.530  99.745   0.640  99.787   0.650  99.830   0.650  99.872   0.655  99.915
0.675  99.957   0.760 100.000
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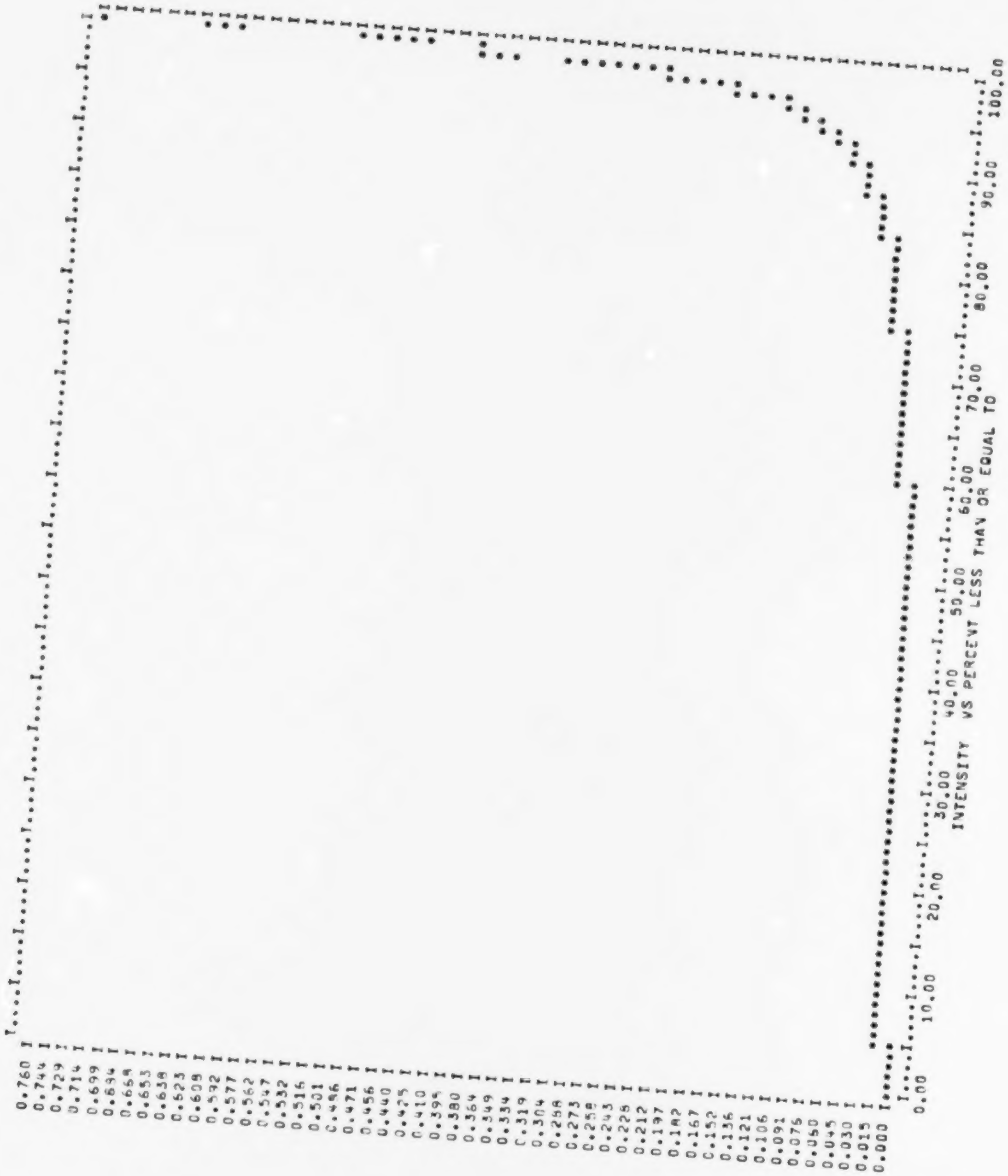
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100.00
INTENSITY VS PERCENT LESS THAN OR EQUAL TO

RETURN PERIOD (IN YEARS) FOR INTENSITY

VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD
0.760	26.000	0.675	13.000	0.655	8.666	0.650	6.500	0.550	5.200	0.640	4.333	0.530	3.714	0.520	3.250
0.503	2.088	0.490	2.600	0.475	2.363	0.420	2.166	0.420	2.000	0.416	1.857	0.412	1.733	0.390	1.625
0.390	1.529	0.350	1.444	0.350	1.368	0.350	1.300	0.345	1.238	0.341	1.181	0.330	1.130	0.325	1.083
0.320	1.040	0.302	1.000	0.290	0.962	0.280	0.928	0.276	0.896	0.275	0.866	0.272	0.838	0.270	0.812
0.270	0.787	0.270	0.754	0.266	0.742	0.265	0.722	0.260	0.702	0.240	0.684	0.240	0.666	0.235	0.650
0.233	0.634	0.230	0.619	0.230	0.604	0.228	0.590	0.220	0.577	0.216	0.565	0.216	0.553	0.213	0.541
0.210	0.530	0.210	0.520	0.201	0.509	0.200	0.500	0.200	0.490	0.200	0.481	0.200	0.472	0.200	0.464
0.200	0.456	0.195	0.448	0.191	0.440	0.190	0.433	0.190	0.426	0.190	0.419	0.190	0.412	0.183	0.406
0.180	0.400	0.180	0.393	0.176	0.389	0.172	0.382	0.170	0.376	0.170	0.371	0.170	0.366	0.167	0.361
0.167	0.356	0.165	0.351	0.163	0.346	0.160	0.342	0.160	0.337	0.160	0.333	0.160	0.329	0.160	0.325
0.155	0.320	0.155	0.317	0.154	0.313	0.150	0.309	0.147	0.305	0.146	0.302	0.142	0.298	0.140	0.295
0.140	0.292	0.140	0.288	0.140	0.285	0.140	0.282	0.140	0.279	0.140	0.276	0.133	0.273	0.138	0.270
0.137	0.268	0.136	0.265	0.136	0.262	0.135	0.260	0.135	0.257	0.133	0.254	0.130	0.252	0.130	0.250
0.130	0.247	0.130	0.245	0.130	0.242	0.130	0.240	0.130	0.238	0.130	0.236	0.130	0.234	0.130	0.232
0.130	0.230	0.130	0.228	0.128	0.226	0.127	0.224	0.126	0.222	0.126	0.220	0.125	0.218	0.125	0.216
0.125	0.214	0.123	0.213	0.123	0.211	0.123	0.209	0.120	0.208	0.120	0.206	0.120	0.204	0.120	0.203
0.120	0.201	0.120	0.200	0.120	0.198	0.120	0.196	0.120	0.195	0.120	0.194	0.120	0.192	0.120	0.191
0.120	0.189	0.120	0.188	0.118	0.187	0.115	0.185	0.115	0.184	0.114	0.183	0.112	0.181	0.112	0.180
0.110	0.179	0.110	0.178	0.110	0.176	0.110	0.175	0.110	0.174	0.110	0.173	0.107	0.172	0.106	0.171
0.106	0.169	0.106	0.168	0.106	0.167	0.105	0.165	0.105	0.165	0.105	0.164	0.105	0.163	0.105	0.162
0.100	0.161	0.100	0.160	0.100	0.159	0.100	0.158	0.100	0.157	0.100	0.156	0.100	0.155	0.100	0.154
0.100	0.153	0.100	0.152	0.097	0.152	0.097	0.151	0.096	0.150	0.096	0.149	0.095	0.148	0.095	0.147
0.095	0.146	0.095	0.146	0.095	0.145	0.095	0.144	0.095	0.143	0.095	0.142	0.094	0.142	0.092	0.141
0.092	0.140	0.092	0.139	0.091	0.139	0.090	0.138	0.090	0.137	0.090	0.136	0.090	0.136	0.090	0.135
0.090	0.134	0.090	0.134	0.090	0.133	0.090	0.132	0.090	0.131	0.090	0.131	0.090	0.130	0.090	0.130
0.088	0.129	0.088	0.128	0.087	0.128	0.087	0.127	0.086	0.126	0.085	0.126	0.085	0.125	0.085	0.125
0.085	0.124	0.085	0.123	0.084	0.123	0.084	0.122	0.083	0.122	0.083	0.121	0.082	0.120	0.082	0.120
0.082	0.119	0.080	0.119	0.080	0.118	0.080	0.118	0.080	0.117	0.080	0.117	0.080	0.116	0.080	0.116
0.080	0.115	0.080	0.115	0.080	0.114	0.080	0.114	0.080	0.113	0.080	0.113	0.080	0.112	0.080	0.112
0.080	0.111	0.077	0.111	0.077	0.110	0.077	0.110	0.077	0.109	0.076	0.109	0.076	0.108	0.076	0.108
0.076	0.107	0.076	0.107	0.075	0.106	0.075	0.106	0.075	0.106	0.075	0.105	0.074	0.105	0.074	0.104
0.074	0.104	0.073	0.104	0.073	0.103	0.073	0.103	0.073	0.102	0.073	0.102	0.072	0.101	0.072	0.101
0.071	0.101	0.071	0.100	0.070	0.100	0.070	0.100	0.070	0.099	0.070	0.099	0.070	0.099	0.070	0.098
0.070	0.098	0.070	0.097	0.070	0.097	0.070	0.097	0.070	0.096	0.070	0.096	0.070	0.095	0.070	0.095
0.070	0.095	0.070	0.094	0.070	0.094	0.070	0.094	0.070	0.093	0.070	0.093	0.070	0.093	0.067	0.092
0.067	0.092	0.067	0.092	0.067	0.091	0.067	0.091	0.066	0.091	0.066	0.090	0.065	0.090	0.065	0.090
0.065	0.089	0.065	0.089	0.065	0.089	0.065	0.089	0.065	0.088	0.065	0.088	0.065	0.088	0.065	0.087
0.064	0.087	0.063	0.087	0.063	0.086	0.063	0.086	0.063	0.086	0.063	0.086	0.062	0.085	0.062	0.085
0.062	0.085	0.061	0.084	0.061	0.084	0.061	0.084	0.060	0.084	0.060	0.083	0.060	0.083	0.060	0.083
0.060	0.083	0.060	0.082	0.060	0.082	0.060	0.082	0.060	0.082	0.060	0.081	0.060	0.081	0.060	0.081
0.060	0.080	0.060	0.080	0.060	0.080	0.060	0.080	0.060	0.080	0.060	0.079	0.060	0.079	0.060	0.079
0.060	0.079	0.060	0.078	0.060	0.078	0.060	0.078	0.060	0.078	0.060	0.077	0.060	0.077	0.060	0.077
0.060	0.077	0.060	0.076	0.060	0.076	0.060	0.076	0.060	0.076	0.060	0.076	0.060	0.075	0.060	0.075
0.059	0.075	0.058	0.075	0.057	0.074	0.057	0.074	0.056	0.074	0.056	0.074	0.056	0.074	0.056	0.073
0.056	0.073	0.056	0.073	0.056	0.073	0.056	0.073	0.056	0.072	0.056	0.072	0.056	0.072	0.055	0.072
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0.054	0.068	0.054	0.068	0.054	0.068	0.054	0.068	0.053	0.068	0.053	0.068	0.053	0.067	0.053	0.067
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0.052	0.066	0.052	0.065	0.052	0.065	0.052	0.065	0.051	0.065	0.051	0.065	0.051	0.065	0.051	0.065
0.051	0.064	0.050	0.064	0.050	0.064	0.050	0.064	0.050	0.064	0.050	0.064	0.050	0.063	0.050	0.063
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0.050	0.062	0.050	0.062	0.050	0.062	0.050	0.061	0.050	0.061	0.050	0.061	0.050	0.061	0.050	0.061

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0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014
0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014
0.010	0.014	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012
0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.012	0.010	0.011	0.010	0.011
0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011
0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011
0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011
0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011
0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.010	0.011	0.009	0.011
0.009	0.011	0.009	0.011	0.009	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011
0.008	0.011	0.008	0.011	0.008	0.011	0.009	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011
0.008	0.011	0.009	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011
0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011
0.008	0.011	0.007	0.011	0.007	0.011	0.007	0.011	0.007	0.011	0.007	0.011	0.007	0.011	0.007	0.011

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0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011
0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011
0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011
0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011   0.007   0.011
0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011
0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011
0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.005   0.011   0.006   0.011
0.006   0.011   0.006   0.011   0.005   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.005   0.011   0.006   0.011
0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.005   0.011   0.006   0.011
0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011   0.006   0.011
0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011
0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011
0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011   0.005   0.011
0.004   0.011   0.004   0.011
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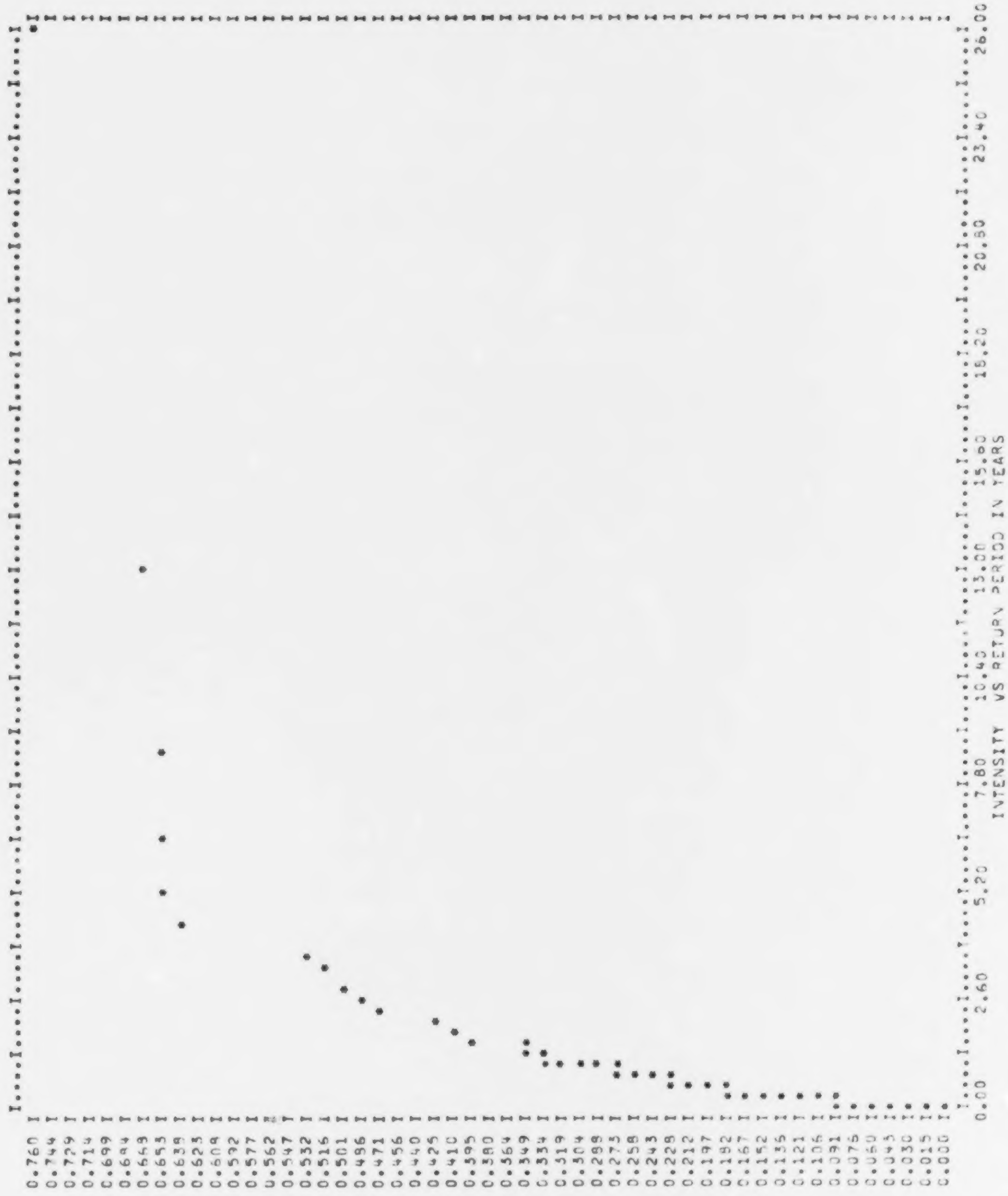
INTENSITY VS RETURN PERIOD IN YEARS
0.00
2.60
5.20
7.80
10.40
13.00
15.60
18.20
20.80
23.40
26.00
0.760
0.744
0.729
0.714
0.699
0.684
0.669
0.653
0.638
0.623
0.608
0.592
0.577
0.562
0.547
0.532
0.516
0.501
0.486
0.471
0.456
0.440
0.425
0.410
0.395
0.380
0.364
0.349
0.334
0.319
0.304
0.289
0.273
0.258
0.243
0.228
0.212
0.197
0.182
0.167
0.152
0.136
0.121
0.106
0.091
0.076
0.060
0.045
0.030
0.015
0.000

PROBABILITY ANALYSIS-VOLUME

PERCENTAGE OF OCCURRENCE LESS THAN OR EQUAL TO THE GIVEN VALUE OF VOLUME

VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT
0.010	0.042	0.010	0.084	0.010	0.127	0.010	0.169	0.010	0.212	0.010	0.254	0.010	0.297	0.010	0.339
0.010	0.382	0.010	0.424	0.010	0.467	0.010	0.509	0.010	0.552	0.010	0.594	0.010	0.637	0.010	0.679
0.010	0.722	0.010	0.764	0.010	0.807	0.010	0.849	0.010	0.892	0.010	0.934	0.010	0.977	0.010	1.019
0.010	1.062	0.010	1.104	0.010	1.146	0.010	1.189	0.010	1.231	0.010	1.274	0.010	1.316	0.010	1.359
0.010	1.401	0.010	1.444	0.010	1.486	0.010	1.529	0.010	1.571	0.010	1.614	0.010	1.656	0.010	1.699
0.010	1.741	0.010	1.784	0.010	1.826	0.010	1.869	0.010	1.911	0.010	1.954	0.010	1.996	0.010	2.039
0.010	2.081	0.010	2.124	0.010	2.166	0.010	2.209	0.010	2.251	0.010	2.293	0.010	2.336	0.010	2.378
0.010	2.421	0.010	2.463	0.010	2.506	0.010	2.548	0.010	2.591	0.010	2.633	0.010	2.676	0.010	2.718
0.010	2.761	0.010	2.803	0.010	2.846	0.010	2.888	0.010	2.931	0.010	2.973	0.010	3.016	0.010	3.058
0.010	3.101	0.010	3.143	0.010	3.186	0.010	3.228	0.010	3.271	0.010	3.313	0.010	3.355	0.010	3.398
0.010	3.440	0.010	3.483	0.010	3.525	0.010	3.568	0.010	3.610	0.010	3.653	0.010	3.695	0.010	3.738
0.010	3.780	0.010	3.823	0.010	3.865	0.010	3.908	0.010	3.950	0.010	3.993	0.010	4.035	0.010	4.078
0.010	4.120	0.010	4.163	0.010	4.205	0.010	4.248	0.010	4.290	0.010	4.333	0.010	4.375	0.010	4.418
0.010	4.460	0.010	4.502	0.010	4.545	0.010	4.587	0.010	4.630	0.010	4.672	0.010	4.715	0.010	4.757
0.010	4.800	0.010	4.842	0.010	4.885	0.010	4.927	0.010	4.970	0.010	5.012	0.010	5.055	0.010	5.097
0.010	5.140	0.010	5.182	0.010	5.225	0.010	5.267	0.010	5.310	0.010	5.352	0.010	5.395	0.010	5.437
0.010	5.480	0.010	5.522	0.010	5.564	0.010	5.607	0.010	5.649	0.010	5.692	0.010	5.734	0.010	5.777
0.010	5.819	0.010	5.862	0.010	5.904	0.010	5.947	0.010	5.989	0.010	6.032	0.010	6.074	0.010	6.117
0.010	6.159	0.010	6.202	0.010	6.244	0.010	6.287	0.010	6.329	0.010	6.372	0.010	6.414	0.010	6.457
0.010	6.499	0.010	6.542	0.010	6.584	0.010	6.627	0.010	6.669	0.010	6.711	0.010	6.754	0.010	6.796
0.010	6.839	0.010	6.881	0.010	6.924	0.010	6.966	0.010	7.009	0.010	7.051	0.010	7.094	0.010	7.136
0.010	7.179	0.010	7.221	0.010	7.264	0.010	7.306	0.010	7.349	0.010	7.391	0.010	7.434	0.010	7.476
0.010	7.519	0.010	7.561	0.010	7.604	0.010	7.646	0.010	7.689	0.010	7.731	0.010	7.774	0.010	7.816
0.010	7.858	0.010	7.901	0.010	7.943	0.010	7.986	0.010	8.028	0.010	8.071	0.010	8.113	0.010	8.156
0.010	8.198	0.010	8.241	0.010	8.283	0.010	8.326	0.010	8.368	0.010	8.411	0.010	8.453	0.010	8.496
0.010	8.538	0.010	8.581	0.010	8.623	0.010	8.666	0.010	8.708	0.010	8.751	0.010	8.793	0.010	8.836
0.010	8.878	0.010	8.920	0.010	8.963	0.010	9.005	0.010	9.048	0.010	9.090	0.010	9.133	0.010	9.175
0.010	9.218	0.010	9.260	0.010	9.303	0.010	9.345	0.010	9.388	0.010	9.430	0.010	9.473	0.010	9.515
0.010	9.558	0.010	9.600	0.010	9.643	0.010	9.685	0.010	9.728	0.010	9.770	0.010	9.813	0.010	9.855
0.010	9.898	0.010	9.940	0.010	9.983	0.010	10.025	0.010	10.067	0.010	10.110	0.010	10.152	0.010	10.195
0.010	10.237	0.010	10.280	0.010	10.322	0.010	10.365	0.010	10.407	0.010	10.450	0.010	10.492	0.010	10.535
0.010	10.577	0.010	10.620	0.010	10.662	0.010	10.705	0.010	10.747	0.010	10.790	0.010	10.832	0.010	10.875
0.010	10.917	0.010	10.960	0.010	11.002	0.010	11.045	0.010	11.087	0.010	11.129	0.010	11.172	0.010	11.214
0.010	11.257	0.010	11.299	0.010	11.342	0.010	11.384	0.010	11.427	0.010	11.469	0.010	11.512	0.010	11.554
0.010	11.597	0.010	11.639	0.010	11.682	0.010	11.724	0.010	11.767	0.010	11.809	0.010	11.852	0.010	11.894
0.010	11.937	0.010	11.979	0.010	12.022	0.010	12.064	0.010	12.107	0.010	12.149	0.010	12.192	0.010	12.234
0.010	12.276	0.010	12.319	0.010	12.361	0.010	12.404	0.010	12.446	0.010	12.489	0.010	12.531	0.010	12.574
0.010	12.616	0.010	12.659	0.010	12.701	0.010	12.744	0.010	12.786	0.010	12.829	0.010	12.871	0.010	12.914
0.010	12.956	0.010	12.999	0.010	13.041	0.010	13.084	0.010	13.126	0.010	13.169	0.010	13.211	0.010	13.254
0.010	13.296	0.010	13.338	0.010	13.381	0.010	13.423	0.010	13.466	0.010	13.508	0.010	13.551	0.010	13.593
0.010	13.636	0.010	13.678	0.010	13.721	0.010	13.763	0.010	13.806	0.010	13.848	0.010	13.891	0.010	13.933
0.010	13.976	0.010	14.018	0.010	14.061	0.010	14.103	0.010	14.146	0.010	14.188	0.010	14.231	0.010	14.273
0.010	14.316	0.010	14.358	0.010	14.401	0.010	14.443	0.010	14.485	0.010	14.528	0.010	14.570	0.010	14.613
0.010	14.656	0.010	14.698	0.010	14.740	0.010	14.783	0.010	14.825	0.010	14.868	0.010	14.910	0.010	14.953
0.010	14.995	0.010	15.038	0.010	15.080	0.010	15.123	0.010	15.165	0.010	15.208	0.010	15.250	0.010	15.293
0.010	15.335	0.010	15.378	0.010	15.420	0.010	15.463	0.010	15.505	0.010	15.548	0.010	15.590	0.010	15.632
0.010	15.675	0.010	15.717	0.010	15.760	0.010	15.802	0.010	15.845	0.010	15.887	0.010	15.930	0.010	15.972
0.010	16.015	0.010	16.057	0.010	16.100	0.010	16.142	0.010	16.185	0.010	16.227	0.010	16.270	0.010	16.312
0.010	16.355	0.010	16.397	0.010	16.440	0.010	16.482	0.010	16.525	0.010	16.567	0.010	16.610	0.010	16.652
0.010	16.694	0.010	16.737	0.010	16.779	0.010	16.822	0.010	16.864	0.010	16.907	0.010	16.949	0.010	16.992
0.010	17.034	0.010	17.077	0.010	17.119	0.010	17.162	0.010	17.204	0.010	17.247	0.010	17.289	0.010	17.332

```
0.010  17.374   0.010  17.417   0.010  17.459   0.010  17.502   0.010  17.544   0.010  17.587   0.010  17.629   0.010  17.672
0.010  17.714   0.010  17.757   0.010  17.799   0.010  17.841   0.010  17.884   0.010  17.926   0.010  17.969   0.010  18.011
0.010  18.054   0.010  18.096   0.010  18.139   0.010  18.181   0.010  18.224   0.010  18.266   0.010  18.309   0.010  18.351
0.010  18.394   0.010  18.436   0.010  18.479   0.010  18.521   0.010  18.564   0.010  18.606   0.010  18.649   0.010  18.691
0.010  18.734   0.010  18.776   0.010  18.819   0.010  18.861   0.010  18.903   0.010  18.946   0.010  18.988   0.010  19.031
0.010  19.073   0.010  19.116   0.010  19.158   0.010  19.201   0.010  19.243   0.010  19.286   0.010  19.328   0.010  19.371
0.010  19.413   0.010  19.456   0.010  19.498   0.010  19.541   0.010  19.583   0.010  19.626   0.010  19.668   0.010  19.711
0.010  19.753   0.010  19.796   0.010  19.838   0.010  19.881   0.010  19.923   0.010  19.966   0.010  20.008   0.010  20.050
0.010  20.093   0.010  20.135   0.010  20.178   0.010  20.220   0.010  20.263   0.010  20.305   0.010  20.348   0.010  20.390
0.010  20.433   0.010  20.475   0.010  20.518   0.010  20.560   0.010  20.603   0.010  20.645   0.010  20.688   0.010  20.730
0.010  20.773   0.010  20.815   0.010  20.858   0.010  20.900   0.010  20.943   0.010  20.985   0.010  21.028   0.010  21.070
0.010  21.113   0.010  21.155   0.010  21.197   0.010  21.240   0.010  21.282   0.010  21.325   0.010  21.367   0.010  21.410
0.010  21.452   0.010  21.495   0.010  21.537   0.010  21.580   0.010  21.622   0.010  21.665   0.010  21.707   0.010  21.750
0.010  21.792   0.010  21.835   0.010  21.877   0.010  21.920   0.010  21.962   0.010  22.005   0.010  22.047   0.010  22.090
0.010  22.132   0.010  22.175   0.010  22.217   0.010  22.259   0.010  22.302   0.010  22.344   0.010  22.387   0.010  22.429
0.010  22.472   0.010  22.514   0.010  22.557   0.010  22.599   0.010  22.642   0.010  22.684   0.010  22.727   0.010  22.769
0.020  22.812   0.020  22.854   0.020  22.897   0.020  22.939   0.020  22.982   0.020  23.024   0.020  23.067   0.020  23.109
0.020  23.152   0.020  23.194   0.020  23.237   0.020  23.279   0.020  23.322   0.020  23.364   0.020  23.406   0.020  23.449
0.020  23.491   0.020  23.534   0.020  23.576   0.020  23.619   0.020  23.661   0.020  23.704   0.020  23.746   0.020  23.789
0.020  23.831   0.020  23.874   0.020  23.916   0.020  23.959   0.020  24.001   0.020  24.044   0.020  24.086   0.020  24.129
0.020  24.171   0.020  24.214   0.020  24.256   0.020  24.299   0.020  24.341   0.020  24.384   0.020  24.426   0.020  24.469
0.020  24.511   0.020  24.553   0.020  24.596   0.020  24.638   0.020  24.681   0.020  24.723   0.020  24.766   0.020  24.808
0.020  24.851   0.020  24.893   0.020  24.936   0.020  24.978   0.020  25.021   0.020  25.063   0.020  25.106   0.020  25.148
0.020  25.191   0.020  25.233   0.020  25.276   0.020  25.318   0.020  25.361   0.020  25.403   0.020  25.446   0.020  25.488
0.020  25.531   0.020  25.573   0.020  25.615   0.020  25.658   0.020  25.700   0.020  25.743   0.020  25.785   0.020  25.828
0.020  25.870   0.020  25.913   0.020  25.955   0.020  25.998   0.020  26.040   0.020  26.083   0.020  26.125   0.020  26.168
0.020  26.210   0.020  26.253   0.020  26.295   0.020  26.338   0.020  26.380   0.020  26.423   0.020  26.465   0.020  26.508
0.020  26.550   0.020  26.593   0.020  26.635   0.020  26.677   0.020  26.720   0.020  26.762   0.020  26.805   0.020  26.847
0.020  26.890   0.020  26.932   0.020  26.975   0.020  27.017   0.020  27.060   0.020  27.102   0.020  27.145   0.020  27.187
0.020  27.230   0.020  27.272   0.020  27.315   0.020  27.357   0.020  27.400   0.020  27.442   0.020  27.485   0.020  27.527
0.020  27.570   0.020  27.612   0.020  27.655   0.020  27.697   0.020  27.740   0.020  27.782   0.020  27.824   0.020  27.867
0.020  27.909   0.020  27.952   0.020  27.994   0.020  28.037   0.020  28.079   0.020  28.122   0.020  28.164   0.020  28.207
0.020  28.249   0.020  28.292   0.020  28.334   0.020  28.377   0.020  28.419   0.020  28.462   0.020  28.504   0.020  28.547
0.020  28.589   0.020  28.632   0.020  28.674   0.020  28.717   0.020  28.759   0.020  28.802   0.020  28.844   0.020  28.887
0.020  28.929   0.020  28.971   0.020  29.014   0.020  29.056   0.020  29.099   0.020  29.141   0.020  29.184   0.020  29.226
0.020  29.269   0.020  29.311   0.020  29.354   0.020  29.396   0.020  29.439   0.020  29.481   0.020  29.524   0.020  29.566
0.020  29.609   0.020  29.651   0.020  29.694   0.020  29.736   0.020  29.779   0.020  29.821   0.020  29.864   0.020  29.906
0.020  29.949   0.020  29.991   0.020  30.033   0.020  30.076   0.020  30.118   0.020  30.161   0.020  30.203   0.020  30.246
0.020  30.288   0.020  30.331   0.020  30.373   0.020  30.416   0.020  30.458   0.020  30.501   0.020  30.543   0.020  30.586
0.020  30.628   0.020  30.671   0.020  30.713   0.020  30.756   0.020  30.798   0.020  30.841   0.020  30.883   0.020  30.925
0.020  30.968   0.020  31.011   0.020  31.053   0.020  31.096   0.020  31.138   0.020  31.180   0.020  31.223   0.020  31.265
0.020  31.308   0.020  31.350   0.020  31.393   0.020  31.435   0.020  31.478   0.020  31.520   0.020  31.563   0.020  31.605
0.020  31.648   0.020  31.690   0.020  31.733   0.020  31.775   0.020  31.818   0.020  31.860   0.020  31.903   0.020  31.945
0.020  31.988   0.020  32.030   0.020  32.073   0.020  32.115   0.020  32.158   0.020  32.200   0.020  32.242   0.020  32.285
0.020  32.327   0.020  32.370   0.020  32.412   0.020  32.455   0.020  32.497   0.020  32.540   0.020  32.582   0.020  32.625
0.020  32.667   0.020  32.710   0.020  32.752   0.020  32.795   0.020  32.837   0.020  32.880   0.020  32.922   0.020  32.965
0.020  33.007   0.020  33.050   0.020  33.092   0.020  33.135   0.020  33.177   0.020  33.220   0.020  33.262   0.020  33.305
0.020  33.347   0.020  33.389   0.020  33.432   0.020  33.474   0.020  33.517   0.020  33.559   0.020  33.602   0.020  33.644
0.020  33.687   0.020  33.729   0.020  33.772   0.020  33.814   0.020  33.857   0.020  33.899   0.020  33.942   0.020  33.984
0.020  34.027   0.020  34.069   0.020  34.112   0.020  34.154   0.020  34.197   0.020  34.239   0.020  34.282   0.020  34.324
0.020  34.367   0.020  34.409   0.020  34.452   0.020  34.494   0.020  34.536   0.020  34.579   0.020  34.621   0.020  34.664
0.020  34.706   0.020  34.749   0.020  34.791   0.020  34.834   0.020  34.876   0.020  34.919   0.020  34.961   0.020  35.004
0.020  35.046   0.020  35.089   0.020  35.131   0.020  35.174   0.020  35.216   0.020  35.259   0.020  35.301   0.020  35.344
0.020  35.386   0.020  35.429   0.020  35.471   0.020  35.514   0.020  35.556   0.020  35.598   0.020  35.641   0.020  35.683
0.020  35.726   0.020  35.768   0.020  35.811   0.020  35.853   0.020  35.896   0.020  35.938   0.020  35.981   0.020  36.023
0.020  36.066   0.020  36.108   0.020  36.151   0.030  36.193   0.030  36.236   0.030  36.278   0.030  36.321   0.030  36.363
0.030  36.406   0.030  36.448   0.030  36.491   0.030  36.533   0.030  36.576   0.030  36.618   0.030  36.661   0.030  36.703
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0.030  36.745    0.030  36.788    0.030  36.830    0.030  36.873    0.030  36.915    0.030  36.958    0.030  37.000    0.030  37.043
0.030  37.085    0.030  37.128    0.030  37.170    0.030  37.213    0.030  37.255    0.030  37.298    0.030  37.340    0.030  37.383
0.030  37.425    0.030  37.468    0.030  37.510    0.030  37.553    0.030  37.595    0.030  37.638    0.030  37.680    0.030  37.723
0.030  37.765    0.030  37.807    0.030  37.850    0.030  37.892    0.030  37.935    0.030  37.977    0.030  38.020    0.030  38.062
0.030  38.105    0.030  38.147    0.030  38.190    0.030  38.232    0.030  38.275    0.030  38.317    0.030  38.360    0.030  38.402
0.030  38.445    0.030  38.487    0.030  38.530    0.030  38.572    0.030  38.615    0.030  38.657    0.030  38.700    0.030  38.742
0.030  38.785    0.030  38.827    0.030  38.870    0.030  38.912    0.030  38.954    0.030  38.997    0.030  39.039    0.030  39.082
0.030  39.124    0.030  39.167    0.030  39.209    0.030  39.252    0.030  39.294    0.030  39.337    0.030  39.379    0.030  39.422
0.030  39.464    0.030  39.507    0.030  39.549    0.030  39.592    0.030  39.634    0.030  39.677    0.030  39.719    0.030  39.762
0.030  39.804    0.030  39.847    0.030  39.889    0.030  39.932    0.030  39.974    0.030  40.016    0.030  40.059    0.030  40.101
0.030  40.144    0.030  40.186    0.030  40.229    0.030  40.271    0.030  40.314    0.030  40.356    0.030  40.399    0.030  40.441
0.030  40.484    0.030  40.526    0.030  40.569    0.030  40.611    0.030  40.654    0.030  40.696    0.030  40.739    0.030  40.781
0.030  40.824    0.030  40.866    0.030  40.909    0.030  40.951    0.030  40.994    0.030  41.036    0.030  41.079    0.030  41.121
0.030  41.163    0.030  41.206    0.030  41.248    0.030  41.291    0.030  41.333    0.030  41.376    0.030  41.418    0.030  41.461
0.030  41.503    0.030  41.546    0.030  41.588    0.030  41.631    0.030  41.673    0.030  41.716    0.030  41.758    0.030  41.801
0.030  41.843    0.030  41.886    0.030  41.928    0.030  41.971    0.030  42.013    0.030  42.056    0.030  42.098    0.030  42.141
0.030  42.183    0.030  42.226    0.030  42.268    0.030  42.310    0.030  42.353    0.030  42.395    0.030  42.438    0.030  42.480
0.030  42.523    0.030  42.565    0.030  42.608    0.030  42.650    0.030  42.693    0.030  42.735    0.030  42.778    0.030  42.820
0.030  42.863    0.030  42.905    0.030  42.948    0.030  42.990    0.030  43.033    0.030  43.075    0.030  43.118    0.030  43.160
0.030  43.203    0.030  43.245    0.030  43.288    0.030  43.330    0.030  43.372    0.030  43.415    0.030  43.457    0.040  43.500
0.040  43.542    0.040  43.585    0.040  43.627    0.040  43.670    0.040  43.712    0.040  43.755    0.040  43.797    0.040  43.840
0.040  43.882    0.040  43.925    0.040  43.967    0.040  44.010    0.040  44.052    0.040  44.095    0.040  44.137    0.040  44.180
0.040  44.222    0.040  44.265    0.040  44.307    0.040  44.350    0.040  44.392    0.040  44.435    0.040  44.477    0.040  44.519
0.040  44.562    0.040  44.604    0.040  44.647    0.040  44.689    0.040  44.732    0.040  44.774    0.040  44.817    0.040  44.859
0.040  44.902    0.040  44.944    0.040  44.987    0.040  45.029    0.040  45.072    0.040  45.114    0.040  45.157    0.040  45.199
0.040  45.242    0.040  45.284    0.040  45.327    0.040  45.369    0.040  45.412    0.040  45.454    0.040  45.497    0.040  45.539
0.040  45.581    0.040  45.624    0.040  45.666    0.040  45.709    0.040  45.751    0.040  45.794    0.040  45.836    0.040  45.879
0.040  45.921    0.040  45.964    0.040  46.006    0.040  46.049    0.040  46.091    0.040  46.134    0.040  46.176    0.040  46.219
0.040  46.261    0.040  46.304    0.040  46.346    0.040  46.389    0.040  46.431    0.040  46.474    0.040  46.516    0.040  46.559
0.040  46.601    0.040  46.644    0.040  46.686    0.040  46.728    0.040  46.771    0.040  46.813    0.040  46.856    0.040  46.898
0.040  46.941    0.040  46.983    0.040  47.026    0.040  47.068    0.040  47.111    0.040  47.153    0.040  47.196    0.040  47.238
0.040  47.281    0.040  47.323    0.040  47.366    0.040  47.408    0.040  47.451    0.040  47.493    0.040  47.536    0.040  47.578
0.040  47.621    0.040  47.663    0.040  47.706    0.040  47.748    0.040  47.791    0.040  47.833    0.040  47.875    0.040  47.918
0.040  47.960    0.040  48.003    0.040  48.045    0.040  48.088    0.040  48.130    0.040  48.173    0.040  48.215    0.040  48.258
0.040  48.300    0.040  48.343    0.040  48.385    0.050  48.428    0.050  48.470    0.050  48.513    0.050  48.555    0.050  48.598
0.050  48.640    0.050  48.683    0.050  48.725    0.050  48.768    0.050  48.810    0.050  48.853    0.050  48.895    0.050  48.937
0.050  48.980    0.050  49.022    0.050  49.065    0.050  49.107    0.050  49.150    0.050  49.192    0.050  49.235    0.050  49.277
0.050  49.320    0.050  49.362    0.050  49.405    0.050  49.447    0.050  49.490    0.050  49.532    0.050  49.575    0.050  49.617
0.050  49.660    0.050  49.702    0.050  49.745    0.050  49.787    0.050  49.830    0.050  49.872    0.050  49.915    0.050  49.957
0.050  50.000    0.050  50.042    0.050  50.084    0.050  50.127    0.050  50.169    0.050  50.212    0.050  50.254    0.050  50.297
0.050  50.339    0.050  50.382    0.050  50.424    0.050  50.467    0.050  50.509    0.050  50.552    0.050  50.594    0.050  50.637
0.050  50.679    0.050  50.722    0.050  50.764    0.050  50.807    0.050  50.849    0.050  50.892    0.050  50.934    0.050  50.977
0.050  51.019    0.050  51.062    0.050  51.104    0.050  51.146    0.050  51.189    0.050  51.231    0.050  51.274    0.050  51.316
0.050  51.359    0.050  51.401    0.050  51.444    0.050  51.486    0.050  51.529    0.050  51.571    0.050  51.614    0.050  51.656
0.050  51.699    0.050  51.741    0.050  51.784    0.050  51.826    0.050  51.869    0.050  51.911    0.050  51.954    0.050  51.996
0.050  52.039    0.050  52.081    0.050  52.124    0.050  52.166    0.060  52.209    0.060  52.251    0.060  52.293    0.060  52.336
0.060  52.378    0.060  52.421    0.060  52.463    0.060  52.506    0.060  52.548    0.060  52.591    0.060  52.633    0.060  52.676
0.060  52.718    0.060  52.761    0.060  52.803    0.060  52.846    0.060  52.888    0.060  52.931    0.060  52.973    0.060  53.016
0.060  53.058    0.060  53.101    0.060  53.143    0.060  53.186    0.060  53.228    0.060  53.271    0.060  53.313    0.060  53.355
0.060  53.398    0.060  53.440    0.060  53.483    0.060  53.525    0.060  53.568    0.060  53.610    0.060  53.653    0.060  53.695
0.060  53.738    0.060  53.780    0.060  53.823    0.060  53.865    0.060  53.908    0.060  53.950    0.060  53.993    0.060  54.035
0.060  54.078    0.060  54.120    0.060  54.163    0.060  54.205    0.060  54.248    0.060  54.290    0.060  54.333    0.060  54.375
0.060  54.418    0.060  54.460    0.060  54.502    0.060  54.545    0.060  54.587    0.060  54.630    0.060  54.672    0.060  54.715
0.060  54.757    0.060  54.800    0.060  54.842    0.060  54.885    0.060  54.927    0.060  54.970    0.060  55.012    0.060  55.055
0.060  55.097    0.060  55.140    0.060  55.182    0.060  55.225    0.060  55.267    0.060  55.310    0.060  55.352    0.060  55.395
0.060  55.437    0.060  55.480    0.060  55.522    0.060  55.565    0.060  55.607    0.060  55.649    0.060  55.692    0.060  55.734
0.060  55.777    0.060  55.819    0.060  55.862    0.060  55.904    0.060  55.947    0.060  55.989    0.060  56.032    0.060  56.074
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0.050  56.117   0.060  56.159   0.060  56.202   0.050  56.244   0.050  56.287   0.050  56.329   0.060  56.372   0.060  56.414
0.060  56.457   0.060  56.499   0.060  56.542   0.070  56.584   0.070  56.627   0.070  56.669   0.070  56.711   0.070  56.754
0.070  56.796   0.070  56.839   0.070  56.881   0.070  56.924   0.070  56.966   0.070  57.009   0.070  57.051   0.070  57.094
0.070  57.136   0.070  57.179   0.070  57.221   0.070  57.264   0.070  57.306   0.070  57.349   0.070  57.391   0.070  57.434
0.070  57.476   0.070  57.519   0.070  57.561   0.070  57.604   0.070  57.646   0.070  57.689   0.070  57.731   0.070  57.774
0.070  57.816   0.070  57.858   0.070  57.901   0.070  57.943   0.070  57.986   0.070  58.028   0.070  58.071   0.070  58.113
0.070  58.156   0.070  58.198   0.070  58.241   0.070  58.283   0.070  58.326   0.070  58.368   0.070  58.411   0.070  58.453
0.070  58.496   0.070  58.538   0.070  58.581   0.070  58.623   0.070  58.666   0.070  58.708   0.070  58.751   0.070  58.793
0.070  58.836   0.070  58.878   0.070  58.920   0.070  58.963   0.070  59.005   0.070  59.048   0.070  59.090   0.070  59.133
0.070  59.175   0.070  59.218   0.070  59.260   0.070  59.303   0.070  59.345   0.070  59.388   0.070  59.430   0.070  59.473
0.070  59.515   0.070  59.558   0.070  59.600   0.070  59.643   0.070  59.685   0.080  59.728   0.080  59.770   0.080  59.813
0.080  59.855   0.080  59.898   0.080  59.940   0.080  59.983   0.080  60.025   0.080  60.067   0.080  60.110   0.080  60.152
0.080  60.195   0.080  60.237   0.080  60.280   0.080  60.322   0.080  60.365   0.080  60.407   0.080  60.450   0.080  60.492
0.080  60.535   0.080  60.577   0.080  60.620   0.080  60.662   0.080  60.705   0.080  60.747   0.080  60.790   0.080  60.832
0.080  60.875   0.080  60.917   0.080  60.960   0.080  61.002   0.080  61.045   0.080  61.087   0.080  61.129   0.080  61.172
0.080  61.214   0.080  61.257   0.080  61.299   0.080  61.342   0.080  61.384   0.080  61.427   0.080  61.469   0.080  61.512
0.080  61.554   0.080  61.597   0.080  61.639   0.080  61.682   0.080  61.724   0.080  61.767   0.080  61.809   0.080  61.852
0.080  61.894   0.080  61.937   0.090  61.979   0.090  62.022   0.090  62.064   0.090  62.107   0.090  62.149   0.090  62.192
0.090  62.234   0.090  62.276   0.090  62.319   0.090  62.361   0.090  62.404   0.090  62.446   0.090  62.489   0.090  62.531
0.090  62.574   0.090  62.616   0.090  62.659   0.090  62.701   0.090  62.744   0.090  62.786   0.090  62.829   0.090  62.871
0.090  62.914   0.090  62.956   0.090  62.999   0.090  63.041   0.090  63.084   0.090  63.126   0.090  63.169   0.090  63.211
0.090  63.254   0.090  63.296   0.090  63.339   0.090  63.381   0.090  63.423   0.090  63.466   0.090  63.508   0.090  63.551
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0.090  64.273   0.090  64.316   0.090  64.358   0.100  64.401   0.100  64.443   0.100  64.485   0.100  64.528   0.100  64.570
0.100  64.613   0.100  64.655   0.100  64.698   0.100  64.740   0.100  64.783   0.100  64.825   0.100  64.868   0.100  64.910
0.100  64.953   0.100  64.995   0.100  65.038   0.100  65.080   0.100  65.123   0.100  65.165   0.100  65.208   0.100  65.250
0.100  65.293   0.100  65.335   0.100  65.378   0.100  65.420   0.100  65.463   0.100  65.505   0.100  65.548   0.100  65.590
0.100  65.632   0.100  65.675   0.100  65.717   0.100  65.760   0.100  65.802   0.100  65.845   0.100  65.887   0.100  65.930
0.100  65.972   0.100  66.015   0.100  66.057   0.100  66.100   0.100  66.142   0.100  66.185   0.100  66.227   0.100  66.270
0.100  66.312   0.100  66.355   0.100  66.397   0.100  66.440   0.100  66.482   0.100  66.525   0.110  66.567   0.110  66.610
0.110  66.652   0.110  66.694   0.110  66.737   0.110  66.779   0.110  66.822   0.110  66.864   0.110  66.907   0.110  66.949
0.110  66.992   0.110  67.034   0.110  67.077   0.110  67.119   0.110  67.162   0.110  67.204   0.110  67.247   0.110  67.289
0.110  67.332   0.110  67.374   0.110  67.417   0.110  67.459   0.110  67.502   0.110  67.544   0.110  67.587   0.110  67.629
0.110  67.672   0.110  67.714   0.110  67.757   0.110  67.799   0.110  67.841   0.110  67.884   0.110  67.926   0.110  67.969
0.110  68.011   0.110  68.054   0.110  68.096   0.110  68.139   0.110  68.181   0.110  68.224   0.110  68.266   0.120  68.309
0.120  68.351   0.120  68.394   0.120  68.436   0.120  68.479   0.120  68.521   0.120  68.564   0.120  68.606   0.120  68.649
0.120  68.691   0.120  68.734   0.120  68.776   0.120  68.819   0.120  68.861   0.120  68.904   0.120  68.946   0.120  68.988
0.120  69.031   0.120  69.073   0.120  69.116   0.120  69.158   0.120  69.201   0.120  69.243   0.120  69.286   0.120  69.329
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0.120  69.711   0.120  69.753   0.120  69.796   0.120  69.838   0.120  69.881   0.120  69.923   0.120  69.965   0.120  70.009
0.120  70.050   0.130  70.093   0.130  70.135   0.130  70.178   0.130  70.220   0.130  70.263   0.130  70.305   0.130  70.349
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0.130  71.070   0.130  71.113   0.130  71.155   0.130  71.197   0.130  71.240   0.130  71.282   0.130  71.325   0.130  71.367
0.130  71.410   0.130  71.452   0.130  71.495   0.130  71.537   0.130  71.580   0.130  71.622   0.130  71.665   0.140  71.707
0.140  71.750   0.140  71.792   0.140  71.835   0.140  71.877   0.140  71.920   0.140  71.962   0.140  72.005   0.140  72.047
0.140  72.090   0.140  72.132   0.140  72.175   0.140  72.217   0.140  72.259   0.140  72.302   0.140  72.344   0.140  72.387
0.140  72.429   0.140  72.472   0.140  72.514   0.140  72.557   0.140  72.599   0.140  72.642   0.140  72.684   0.140  72.727
0.140  72.769   0.140  72.812   0.140  72.854   0.140  72.897   0.150  72.939   0.150  72.982   0.150  73.024   0.150  73.067
0.150  73.109   0.150  73.152   0.150  73.194   0.150  73.237   0.150  73.279   0.150  73.322   0.150  73.364   0.150  73.406
0.150  73.449   0.150  73.491   0.150  73.534   0.150  73.576   0.150  73.619   0.150  73.661   0.150  73.704   0.150  73.745
0.150  73.789   0.150  73.831   0.150  73.874   0.160  73.916   0.160  73.959   0.160  74.001   0.160  74.044   0.160  74.086
0.160  74.129   0.160  74.171   0.160  74.214   0.160  74.256   0.160  74.299   0.160  74.341   0.160  74.384   0.160  74.425
0.160  74.469   0.160  74.511   0.160  74.553   0.160  74.596   0.170  74.638   0.170  74.681   0.170  74.723   0.170  74.765
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0.190  76.847   0.190  76.890   0.190  76.932   0.190  76.975   0.190  77.017   0.190  77.060   0.190  77.102   0.190  77.145
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0.190  77.527   0.190  77.570   0.190  77.612   0.190  77.655   0.190  77.697   0.190  77.740   0.190  77.782   0.190  77.824
0.190  77.867   0.200  77.909   0.200  77.952   0.200  77.994   0.200  78.037   0.200  78.079   0.200  78.122   0.200  78.164
0.200  78.207   0.200  78.249   0.200  78.292   0.200  78.334   0.200  78.377   0.200  78.419   0.200  78.462   0.200  78.504
0.200  78.547   0.210  78.589   0.210  78.632   0.210  78.674   0.210  78.717   0.210  78.759   0.210  78.802   0.210  78.844
0.210  78.887   0.210  78.929   0.210  78.971   0.210  79.014   0.210  79.056   0.210  79.099   0.210  79.141   0.210  79.184
0.210  79.226   0.210  79.269   0.210  79.311   0.210  79.354   0.210  79.396   0.220  79.439   0.220  79.481   0.220  79.524
0.220  79.566   0.220  79.609   0.220  79.651   0.220  79.694   0.220  79.736   0.220  79.779   0.220  79.821   0.220  79.864
0.220  79.906   0.220  79.949   0.220  79.991   0.220  80.033   0.220  80.076   0.220  80.118   0.220  80.161   0.220  80.203
0.230  80.246   0.230  80.288   0.230  80.331   0.230  80.373   0.230  80.416   0.230  80.458   0.230  80.501   0.230  80.543
0.230  80.586   0.230  80.628   0.240  80.671   0.240  80.713   0.240  80.756   0.240  80.798   0.240  80.841   0.240  80.883
0.240  80.926   0.240  80.968   0.240  81.011   0.240  81.053   0.240  81.096   0.240  81.138   0.240  81.180   0.240  81.223
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0.260  82.285   0.260  82.327   0.260  82.370   0.260  82.412   0.260  82.455   0.260  82.497   0.270  82.540   0.270  82.582
0.270  82.625   0.270  82.667   0.270  82.710   0.270  82.752   0.270  82.795   0.270  82.837   0.270  82.880   0.270  82.922
0.270  82.965   0.270  83.007   0.270  83.050   0.270  83.092   0.270  83.135   0.270  83.177   0.270  83.220   0.270  83.262
0.270  83.305   0.270  83.347   0.270  83.389   0.280  83.432   0.280  83.474   0.280  83.517   0.280  83.559   0.280  83.602
0.280  83.644   0.280  83.687   0.290  83.729   0.280  83.772   0.280  83.814   0.290  83.857   0.280  83.899   0.280  83.942
0.280  83.984   0.280  84.027   0.290  84.069   0.290  84.112   0.280  84.154   0.290  84.197   0.290  84.239   0.280  84.282
0.290  84.324   0.290  84.367   0.290  84.409   0.290  84.452   0.290  84.494   0.290  84.536   0.290  84.579   0.290  84.621
0.300  84.664   0.300  84.706   0.300  84.749   0.300  84.791   0.300  84.834   0.300  84.876   0.300  84.919   0.300  84.961
0.300  85.004   0.300  85.046   0.310  85.089   0.310  85.131   0.310  85.174   0.310  85.216   0.310  85.259   0.310  85.301
0.310  85.344   0.310  85.386   0.310  85.429   0.310  85.471   0.310  85.514   0.310  85.556   0.320  85.598   0.320  85.641
0.320  85.683   0.320  85.726   0.320  85.769   0.320  85.811   0.320  85.853   0.320  85.896   0.320  85.938   0.320  85.981
0.320  86.023   0.330  86.066   0.330  86.108   0.330  86.151   0.330  86.193   0.330  86.236   0.330  86.278   0.330  86.321
0.330  86.363   0.330  86.406   0.330  86.448   0.330  86.491   0.330  86.533   0.330  86.576   0.330  86.618   0.340  86.661
0.340  86.703   0.340  86.745   0.340  86.788   0.340  86.830   0.340  86.873   0.350  86.915   0.350  86.958   0.350  87.000
0.350  87.043   0.350  87.085   0.350  87.128   0.350  87.170   0.350  87.213   0.350  87.255   0.350  87.298   0.360  87.340
0.360  87.383   0.360  87.425   0.350  87.468   0.360  87.510   0.360  87.553   0.360  87.595   0.360  87.638   0.360  87.680
0.360  87.723   0.360  87.765   0.360  87.807   0.360  87.850   0.360  87.892   0.370  87.935   0.370  87.977   0.370  88.020
0.370  88.062   0.370  88.105   0.370  88.147   0.370  88.190   0.370  88.232   0.370  88.275   0.370  88.317   0.370  88.360
0.380  88.402   0.380  88.445   0.380  88.487   0.380  88.530   0.380  88.572   0.380  88.615   0.380  88.657   0.380  88.700
0.380  88.742   0.380  88.785   0.380  88.827   0.380  88.870   0.380  88.912   0.380  88.954   0.390  88.997   0.390  89.039
0.390  89.082   0.390  89.124   0.390  89.167   0.390  89.209   0.390  89.252   0.400  89.294   0.400  89.337   0.400  89.379
0.400  89.422   0.400  89.464   0.400  89.507   0.400  89.549   0.400  89.592   0.400  89.634   0.400  89.677   0.400  89.719
0.400  89.762   0.400  89.804   0.410  89.847   0.410  89.889   0.410  89.932   0.410  89.974   0.410  90.016   0.420  90.059
0.420  90.101   0.420  90.144   0.420  90.186   0.420  90.229   0.420  90.271   0.420  90.314   0.420  90.356   0.430  90.399
0.430  90.441   0.430  90.484   0.430  90.526   0.430  90.569   0.440  90.611   0.450  90.654   0.450  90.696   0.450  90.739
0.450  90.781   0.450  90.824   0.450  90.866   0.460  90.909   0.460  90.951   0.460  90.994   0.460  91.036   0.460  91.079
0.460  91.121   0.470  91.163   0.470  91.206   0.470  91.248   0.470  91.291   0.470  91.333   0.470  91.376   0.470  91.419
0.470  91.461   0.480  91.503   0.490  91.546   0.490  91.588   0.480  91.631   0.480  91.673   0.490  91.716   0.480  91.758
0.480  91.801   0.490  91.843   0.490  91.886   0.500  91.928   0.500  91.971   0.500  92.013   0.510  92.056   0.510  92.098
0.520  92.141   0.520  92.183   0.530  92.226   0.530  92.268   0.530  92.310   0.530  92.353   0.530  92.395   0.530  92.438
0.540  92.480   0.540  92.523   0.540  92.565   0.540  92.608   0.540  92.650   0.540  92.693   0.540  92.735   0.540  92.778
0.550  92.820   0.550  92.863   0.550  92.905   0.550  92.948   0.550  92.990   0.560  93.033   0.560  93.075   0.560  93.118
0.570  93.160   0.570  93.203   0.570  93.245   0.570  93.288   0.580  93.330   0.590  93.372   0.600  93.415   0.600  93.457
0.600  93.500   0.600  93.542   0.610  93.585   0.610  93.627   0.620  93.670   0.620  93.712   0.620  93.755   0.620  93.797
0.630  93.840   0.640  93.882   0.640  93.925   0.640  93.967   0.640  94.010   0.640  94.052   0.650  94.095   0.650  94.137
0.650  94.180   0.650  94.222   0.650  94.265   0.650  94.307   0.660  94.350   0.660  94.392   0.660  94.435   0.670  94.477
0.670  94.519   0.670  94.562   0.670  94.604   0.680  94.647   0.690  94.689   0.690  94.732   0.690  94.774   0.690  94.817
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0.760  95.539   0.760  95.582   0.750  95.624   0.780  95.666   0.790  95.709   0.790  95.751   0.800  95.794   0.800  95.836
0.800  95.879   0.800  95.921   0.820  95.964   0.820  96.006   0.820  96.049   0.820  96.091   0.830  96.134   0.830  96.176
0.850  96.219   0.850  96.261   0.870  96.304   0.870  96.346   0.870  96.389   0.880  96.431   0.890  96.474   0.910  96.515
0.920  96.559   0.920  96.601   0.930  96.644   0.940  96.686   0.950  96.728   0.950  96.771   0.970  96.813   0.970  96.855
0.980  96.899   0.990  96.941   0.990  96.983   0.990  97.026   1.000  97.068   1.010  97.111   1.010  97.153   1.030  97.195
1.040  97.238   1.050  97.281   1.050  97.323   1.060  97.366   1.070  97.408   1.070  97.451   1.080  97.493   1.080  97.535
1.090  97.578   1.100  97.621   1.110  97.663   1.110  97.706   1.150  97.748   1.160  97.791   1.160  97.833   1.200  97.875
1.200  97.918   1.210  97.960   1.210  98.003   1.240  98.045   1.250  98.088   1.260  98.130   1.280  98.173   1.300  98.215
1.310  98.258   1.350  98.300   1.360  98.343   1.370  98.385   1.380  98.428   1.390  98.470   1.430  98.513   1.430  98.555
1.460  98.598   1.460  98.640   1.490  98.683   1.500  98.725   1.510  98.768   1.510  98.810   1.570  98.853   1.600  98.895
1.610  98.937   1.620  98.980   1.640  99.022   1.660  99.065   1.700  99.107   1.700  99.150   1.740  99.192   1.760  99.235
1.870  99.277   1.950  99.320   1.960  99.362   2.050  99.405   2.060  99.447   2.120  99.490   2.130  99.532   2.150  99.575
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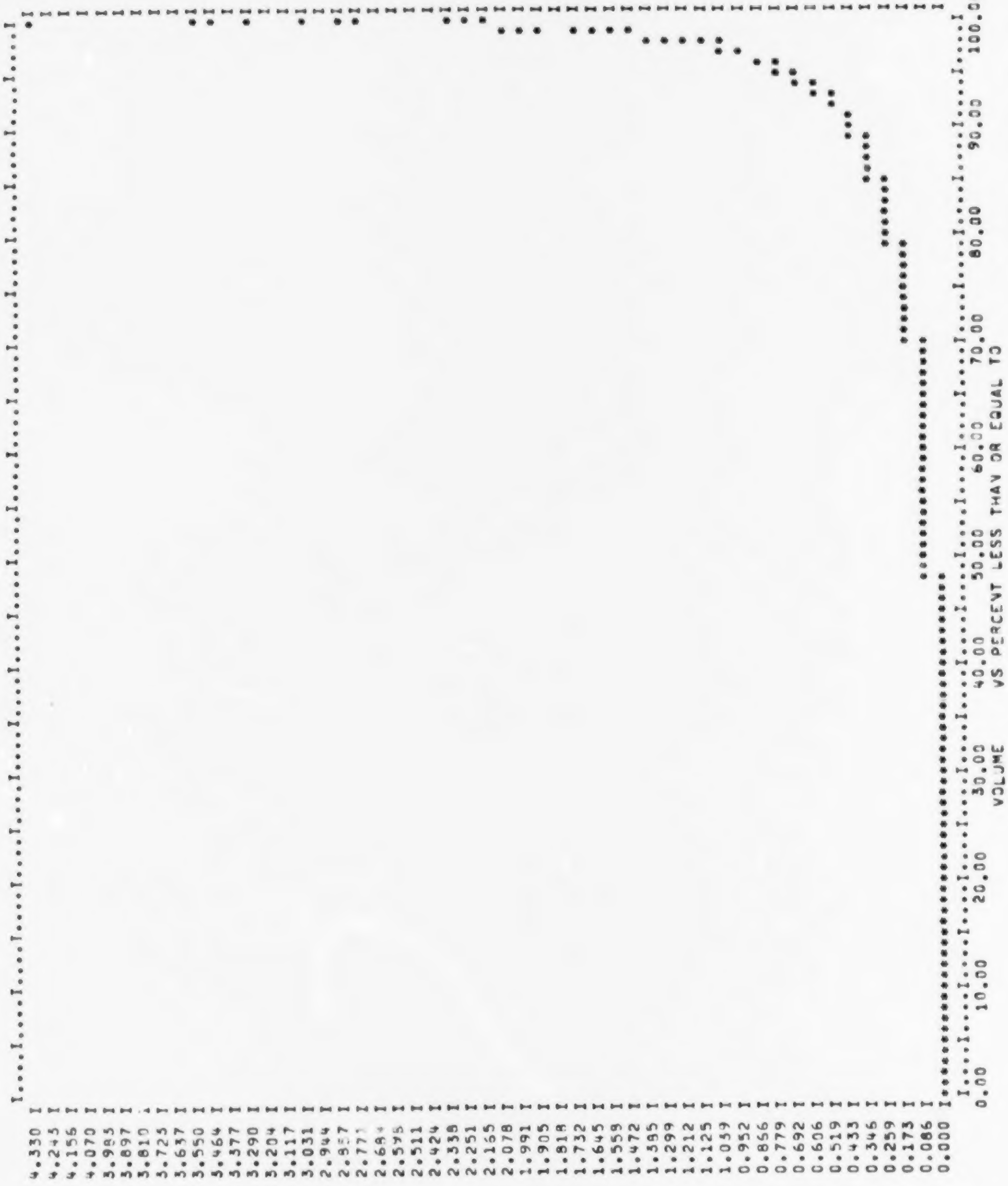
4.330
4.243
4.156
4.070
3.983
3.897
3.810
3.723
3.637
3.550
3.464
3.377
3.290
3.204
3.117
3.031
2.944
2.857
2.771
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2.595
2.511
2.424
2.338
2.251
2.165
2.078
1.991
1.905
1.818
1.732
1.645
1.559
1.472
1.385
1.299
1.212
1.125
1.039
0.952
0.856
0.779
0.692
0.606
0.519
0.433
0.346
0.259
0.173
0.086
0.000
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
VOLUME VS PERCENT LESS THAN OR EQUAL TO

RETURN PERIOD (IN YEARS) FOR VOLUME

VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD	VALUE	PERIOD
4.330	26.000	3.550	13.000	3.430	8.666	3.290	6.500	3.250	5.200	3.040	4.333	2.820	3.714	2.770	3.250
2.380	2.888	2.220	2.600	2.150	2.363	2.130	2.166	2.120	2.000	2.060	1.857	2.050	1.733	1.960	1.625
1.950	1.529	1.870	1.444	1.760	1.368	1.740	1.300	1.700	1.238	1.700	1.181	1.650	1.130	1.640	1.083
1.620	1.040	1.610	1.000	1.600	0.962	1.570	0.928	1.510	0.896	1.510	0.866	1.500	0.838	1.490	0.812
1.460	0.787	1.460	0.754	1.430	0.742	1.430	0.722	1.390	0.702	1.390	0.684	1.370	0.666	1.360	0.650
1.350	0.634	1.310	0.619	1.300	0.604	1.280	0.590	1.260	0.577	1.250	0.565	1.240	0.553	1.210	0.541
1.210	0.530	1.200	0.520	1.200	0.509	1.160	0.500	1.160	0.490	1.150	0.481	1.110	0.472	1.110	0.464
1.100	0.456	1.090	0.448	1.080	0.440	1.080	0.433	1.070	0.426	1.070	0.419	1.060	0.412	1.050	0.406
1.050	0.400	1.040	0.393	1.030	0.388	1.010	0.382	1.010	0.376	1.000	0.371	0.990	0.366	0.990	0.361
0.930	0.356	0.980	0.351	0.970	0.346	0.970	0.342	0.950	0.337	0.950	0.333	0.940	0.329	0.930	0.325
0.920	0.320	0.920	0.317	0.910	0.313	0.890	0.309	0.880	0.305	0.870	0.302	0.870	0.298	0.870	0.295
0.850	0.292	0.850	0.288	0.830	0.285	0.830	0.282	0.820	0.279	0.820	0.276	0.820	0.273	0.820	0.270
0.800	0.268	0.800	0.255	0.800	0.262	0.800	0.260	0.790	0.257	0.790	0.254	0.780	0.252	0.760	0.250
0.760	0.247	0.760	0.245	0.750	0.242	0.750	0.240	0.740	0.238	0.730	0.236	0.720	0.234	0.720	0.232
0.720	0.230	0.720	0.228	0.710	0.226	0.710	0.224	0.710	0.222	0.700	0.220	0.700	0.218	0.700	0.216
0.690	0.214	0.690	0.213	0.690	0.211	0.680	0.209	0.680	0.208	0.690	0.206	0.680	0.204	0.670	0.203
0.670	0.201	0.670	0.200	0.670	0.198	0.660	0.196	0.660	0.195	0.660	0.194	0.650	0.192	0.650	0.191
0.650	0.199	0.650	0.198	0.650	0.197	0.650	0.185	0.640	0.184	0.640	0.183	0.640	0.181	0.640	0.180
0.640	0.179	0.630	0.178	0.620	0.176	0.620	0.175	0.620	0.174	0.620	0.173	0.610	0.172	0.610	0.171
0.600	0.169	0.600	0.168	0.600	0.167	0.600	0.166	0.590	0.165	0.580	0.164	0.570	0.163	0.570	0.162
0.570	0.161	0.570	0.160	0.560	0.159	0.550	0.158	0.560	0.157	0.550	0.156	0.550	0.155	0.550	0.154
0.550	0.153	0.550	0.152	0.540	0.152	0.540	0.151	0.540	0.150	0.540	0.149	0.540	0.148	0.540	0.147
0.540	0.146	0.540	0.146	0.530	0.145	0.530	0.144	0.530	0.143	0.530	0.142	0.530	0.142	0.530	0.141
0.520	0.140	0.520	0.139	0.510	0.139	0.510	0.138	0.500	0.137	0.500	0.136	0.500	0.136	0.490	0.135
0.490	0.134	0.480	0.134	0.480	0.133	0.480	0.132	0.480	0.131	0.480	0.131	0.490	0.130	0.480	0.130
0.480	0.129	0.470	0.128	0.470	0.128	0.470	0.127	0.470	0.126	0.470	0.126	0.470	0.125	0.470	0.125
0.470	0.124	0.460	0.123	0.460	0.123	0.460	0.122	0.460	0.122	0.460	0.121	0.460	0.120	0.450	0.120
0.450	0.119	0.450	0.119	0.450	0.118	0.450	0.118	0.450	0.117	0.440	0.117	0.430	0.116	0.430	0.116
0.430	0.115	0.430	0.115	0.430	0.114	0.420	0.114	0.420	0.113	0.420	0.113	0.420	0.112	0.420	0.112
0.420	0.111	0.420	0.111	0.420	0.110	0.410	0.110	0.410	0.109	0.410	0.109	0.410	0.108	0.410	0.108
0.400	0.107	0.400	0.107	0.400	0.106	0.400	0.106	0.400	0.106	0.400	0.105	0.400	0.105	0.400	0.104
0.400	0.104	0.400	0.104	0.400	0.103	0.400	0.103	0.400	0.102	0.390	0.102	0.390	0.101	0.390	0.101
0.390	0.101	0.390	0.100	0.390	0.100	0.390	0.100	0.380	0.099	0.380	0.099	0.380	0.098	0.380	0.098
0.380	0.098	0.380	0.097	0.380	0.097	0.380	0.097	0.380	0.096	0.380	0.096	0.380	0.095	0.380	0.095
0.380	0.095	0.380	0.094	0.370	0.094	0.370	0.094	0.370	0.093	0.370	0.093	0.370	0.093	0.370	0.092
0.370	0.092	0.370	0.092	0.370	0.091	0.370	0.091	0.370	0.091	0.360	0.090	0.360	0.090	0.360	0.090
0.360	0.089	0.360	0.089	0.360	0.089	0.360	0.089	0.360	0.088	0.360	0.088	0.360	0.088	0.360	0.087
0.360	0.087	0.360	0.087	0.350	0.086	0.350	0.086	0.350	0.086	0.350	0.086	0.350	0.085	0.350	0.085
0.350	0.085	0.350	0.084	0.350	0.084	0.350	0.084	0.350	0.084	0.340	0.083	0.340	0.083	0.340	0.083
0.340	0.083	0.340	0.082	0.340	0.082	0.330	0.082	0.330	0.082	0.330	0.081	0.330	0.081	0.330	0.081
0.330	0.080	0.330	0.080	0.330	0.080	0.330	0.080	0.330	0.080	0.330	0.079	0.330	0.079	0.330	0.079
0.330	0.079	0.320	0.078	0.320	0.078	0.320	0.078	0.320	0.078	0.320	0.077	0.320	0.077	0.320	0.077
0.320	0.077	0.320	0.076	0.320	0.076	0.320	0.076	0.310	0.076	0.310	0.076	0.310	0.075	0.310	0.075
0.310	0.075	0.310	0.075	0.310	0.074	0.310	0.074	0.310	0.074	0.310	0.074	0.310	0.074	0.310	0.073
0.300	0.073	0.300	0.073	0.300	0.073	0.300	0.073	0.300	0.072	0.300	0.072	0.300	0.072	0.300	0.072
0.300	0.072	0.300	0.071	0.290	0.071	0.290	0.071	0.290	0.071	0.290	0.071	0.290	0.070	0.290	0.070
0.290	0.070	0.290	0.070	0.290	0.070	0.280	0.069	0.280	0.069	0.280	0.069	0.290	0.069	0.280	0.069
0.280	0.068	0.280	0.069	0.280	0.068	0.280	0.068	0.280	0.068	0.280	0.068	0.280	0.067	0.280	0.067
0.280	0.067	0.280	0.067	0.240	0.067	0.280	0.067	0.280	0.066	0.280	0.066	0.280	0.066	0.270	0.066
0.270	0.066	0.270	0.065	0.270	0.065	0.270	0.065	0.270	0.065	0.270	0.065	0.270	0.065	0.270	0.065
0.270	0.064	0.270	0.064	0.270	0.064	0.270	0.064	0.270	0.064	0.270	0.064	0.270	0.063	0.270	0.063
0.270	0.063	0.270	0.063	0.270	0.063	0.270	0.063	0.260	0.062	0.260	0.062	0.260	0.062	0.260	0.062
0.260	0.062	0.260	0.062	0.260	0.062	0.260	0.061	0.260	0.061	0.260	0.061	0.260	0.061	0.260	0.061

0.260	0.061	0.260	0.061	0.250	0.060	0.250	0.060	0.250	0.060	0.250	0.060	0.250	0.060	0.250	0.060
0.250	0.060	0.250	0.059	0.250	0.059	0.250	0.059	0.250	0.059	0.240	0.059	0.240	0.059	0.240	0.059
0.240	0.058	0.240	0.058	0.240	0.058	0.240	0.058	0.240	0.058	0.240	0.058	0.240	0.058	0.240	0.058
0.240	0.057	0.240	0.057	0.240	0.057	0.240	0.057	0.240	0.057	0.240	0.057	0.240	0.057	0.240	0.057
0.230	0.056	0.230	0.056	0.230	0.056	0.230	0.056	0.230	0.056	0.230	0.056	0.230	0.056	0.230	0.056
0.230	0.055	0.230	0.055	0.220	0.055	0.220	0.055	0.220	0.055	0.220	0.055	0.220	0.055	0.220	0.055
0.220	0.054	0.220	0.054	0.220	0.054	0.220	0.054	0.220	0.054	0.220	0.054	0.220	0.054	0.220	0.054
0.220	0.054	0.220	0.053	0.220	0.053	0.220	0.053	0.220	0.053	0.210	0.053	0.210	0.053	0.210	0.053
0.210	0.053	0.210	0.053	0.210	0.052	0.210	0.052	0.210	0.052	0.210	0.052	0.210	0.052	0.210	0.052
0.210	0.052	0.210	0.052	0.210	0.052	0.210	0.052	0.210	0.051	0.210	0.051	0.210	0.051	0.210	0.051
0.210	0.051	0.200	0.051	0.200	0.051	0.200	0.051	0.200	0.051	0.200	0.050	0.200	0.050	0.200	0.050
0.200	0.050	0.200	0.050	0.200	0.050	0.200	0.050	0.200	0.050	0.200	0.050	0.200	0.050	0.200	0.050
0.200	0.049	0.190	0.049	0.190	0.049	0.190	0.049	0.190	0.049	0.190	0.049	0.190	0.049	0.190	0.049
0.190	0.049	0.190	0.049	0.190	0.048	0.190	0.048	0.190	0.048	0.190	0.048	0.190	0.048	0.190	0.048
0.190	0.048	0.190	0.048	0.190	0.048	0.190	0.048	0.190	0.048	0.190	0.047	0.180	0.047	0.180	0.047
0.180	0.047	0.180	0.047	0.180	0.047	0.180	0.047	0.180	0.047	0.180	0.047	0.180	0.047	0.180	0.047
0.180	0.047	0.180	0.046	0.180	0.046	0.180	0.046	0.180	0.046	0.180	0.046	0.180	0.046	0.180	0.046
0.180	0.046	0.180	0.046	0.180	0.046	0.180	0.046	0.180	0.046	0.180	0.045	0.180	0.045	0.180	0.045
0.180	0.045	0.180	0.045	0.180	0.045	0.180	0.045	0.180	0.045	0.180	0.045	0.180	0.045	0.180	0.045
0.180	0.045	0.180	0.044	0.170	0.044	0.170	0.044	0.170	0.044	0.170	0.044	0.170	0.044	0.170	0.044
0.170	0.044	0.170	0.044	0.170	0.044	0.170	0.044	0.170	0.044	0.170	0.044	0.170	0.043	0.170	0.043
0.170	0.043	0.170	0.043	0.170	0.043	0.170	0.043	0.170	0.043	0.170	0.043	0.160	0.043	0.160	0.043
0.160	0.043	0.160	0.043	0.160	0.043	0.160	0.043	0.160	0.042	0.160	0.042	0.160	0.042	0.160	0.042
0.160	0.042	0.160	0.042	0.160	0.042	0.160	0.042	0.160	0.042	0.160	0.042	0.160	0.042	0.150	0.042
0.150	0.042	0.150	0.042	0.150	0.042	0.150	0.041	0.150	0.041	0.150	0.041	0.150	0.041	0.150	0.041
0.150	0.041	0.150	0.041	0.150	0.041	0.150	0.041	0.150	0.041	0.150	0.041	0.150	0.041	0.150	0.041
0.150	0.041	0.150	0.041	0.150	0.040	0.150	0.040	0.150	0.040	0.150	0.040	0.140	0.040	0.140	0.040
0.140	0.040	0.140	0.040	0.140	0.040	0.140	0.040	0.140	0.040	0.140	0.040	0.140	0.040	0.140	0.040
0.140	0.040	0.140	0.040	0.140	0.039	0.140	0.039	0.140	0.039	0.140	0.039	0.140	0.039	0.140	0.039
0.140	0.039	0.140	0.039	0.140	0.039	0.140	0.039	0.140	0.039	0.140	0.039	0.140	0.039	0.140	0.039
0.140	0.039	0.140	0.039	0.140	0.038	0.130	0.038	0.130	0.038	0.130	0.038	0.130	0.038	0.130	0.038
0.130	0.038	0.130	0.038	0.130	0.038	0.130	0.038	0.130	0.038	0.130	0.038	0.130	0.038	0.130	0.038
0.130	0.038	0.130	0.038	0.130	0.038	0.130	0.038	0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.037
0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.037
0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.037	0.130	0.036	0.130	0.036
0.130	0.036	0.120	0.036	0.120	0.036	0.120	0.036	0.120	0.036	0.120	0.036	0.120	0.036	0.120	0.036
0.120	0.036	0.120	0.036	0.120	0.036	0.120	0.036	0.120	0.036	0.120	0.036	0.120	0.036	0.120	0.035
0.120	0.036	0.120	0.036	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035
0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035
0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.035	0.120	0.034	0.120	0.034
0.120	0.034	0.120	0.034	0.120	0.034	0.110	0.034	0.110	0.034	0.110	0.034	0.110	0.034	0.110	0.034
0.110	0.034	0.110	0.034	0.110	0.034	0.110	0.034	0.110	0.034	0.110	0.034	0.110	0.034	0.110	0.034
0.110	0.034	0.110	0.034	0.110	0.034	0.110	0.034	0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033
0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033
0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.033
0.110	0.033	0.110	0.033	0.110	0.033	0.110	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032
0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032
0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032
0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.032	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031
0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031
0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031
0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.031	0.100	0.030	0.090	0.030
0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030
0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030
0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030	0.090	0.030
0.090	0.030	0.090	0.030	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029
0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029

0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029
0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029	0.090	0.029
0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028
0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028
0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028
0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028	0.080	0.028
0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027
0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027
0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.080	0.027	0.070	0.027	0.070	0.027	0.070	0.027
0.070	0.027	0.070	0.027	0.070	0.027	0.070	0.027	0.070	0.027	0.070	0.027	0.070	0.027	0.070	0.027
0.070	0.027	0.070	0.027	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026
0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026
0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.025	0.070	0.026	0.070	0.026	0.070	0.026
0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026
0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026	0.070	0.026
0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025
0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025
0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.070	0.025	0.060	0.025
0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025
0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025	0.060	0.025
0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024
0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024
0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024
0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024
0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.024
0.060	0.024	0.060	0.024	0.060	0.024	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023
0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023
0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023
0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023
0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023
0.060	0.023	0.050	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.060	0.023	0.050	0.023	0.050	0.023
0.050	0.023	0.050	0.023	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022
0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022
0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022
0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022
0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022
0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022
0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.022	0.050	0.021	0.050	0.021	0.050	0.021
0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021
0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021
0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021
0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.050	0.021	0.040	0.021
0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021
0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021
0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.021	0.040	0.020	0.040	0.020
0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020
0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020
0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020
0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020
0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020
0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020
0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020
0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.020	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019
0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019
0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019
0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019	0.040	0.019
0.040	0.019	0.040	0.019	0.040	0.019	0.030	0.019	0.030	0.019	0.030	0.019	0.030	0.019	0.030	0.019

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0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019
0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019
0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019
0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019   0.030   0.019
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018
0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.018   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017
0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017
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0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017
0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.030   0.017   0.020   0.017
0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017
0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017
0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017   0.020   0.017
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0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.015   0.020   0.015   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016   0.020   0.016
0.020   0.016   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
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0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
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0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
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0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015
0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.015   0.020   0.014   0.020   0.014   0.020   0.014
0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014
0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014
0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014
0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014
0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014
0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014
0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014   0.020   0.014
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0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014
0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014	0.020	0.014
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0.020	0.014	0.020	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014
0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014
0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014
0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014
0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014	0.010	0.014
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0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
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0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
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0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013	0.010	0.013
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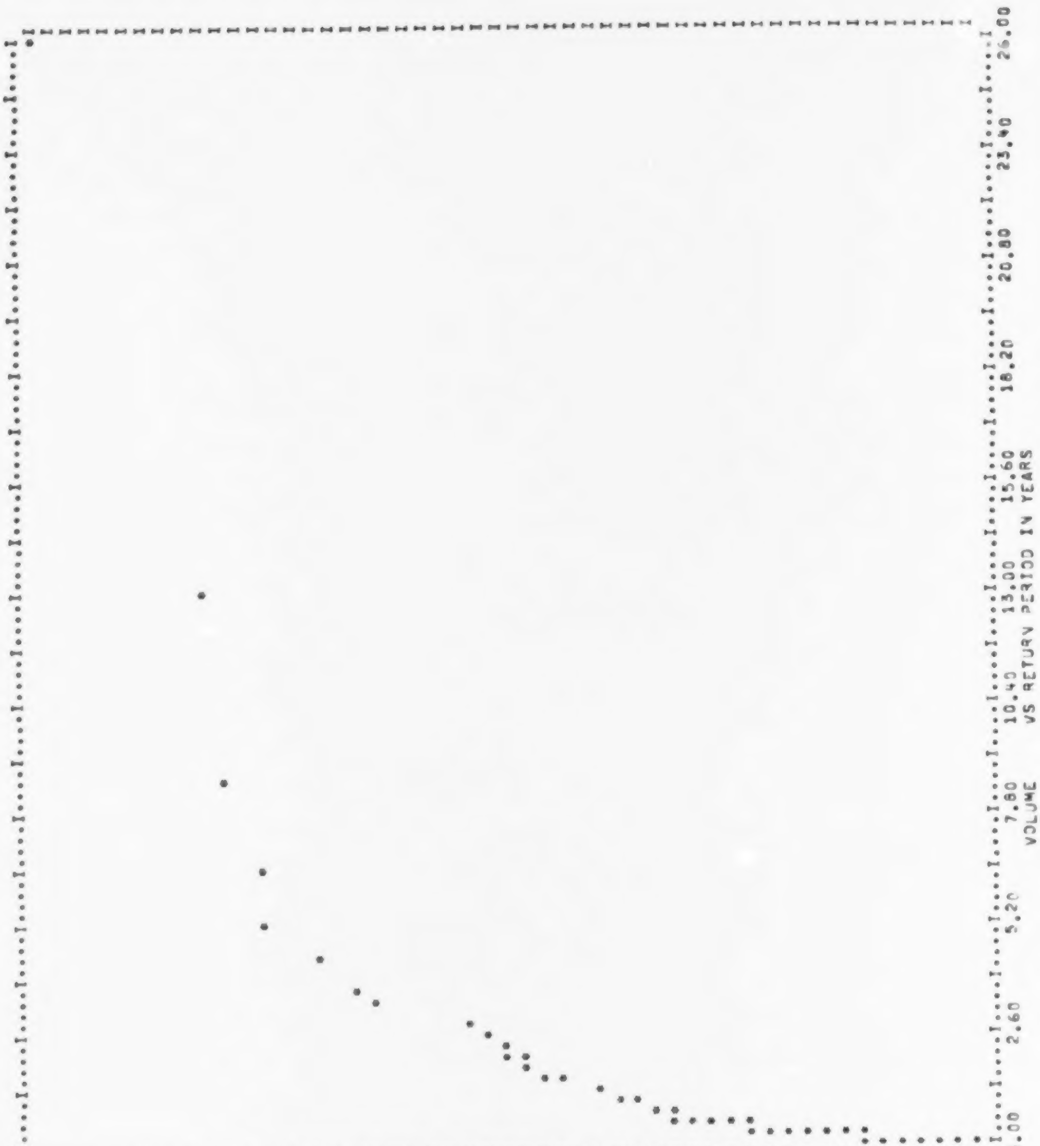
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7.80
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13.00
15.60
18.20
20.80
23.40
26.00
VOLUME VS RETURN PERIOD IN YEARS

PROBABILITY ANALYSIS-DELTA

PERCENTAGE OF OCCURRENCE LESS THAN OR EQUAL TO THE GIVEN VALUE OF DELTA

VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT	VALUE	PCT
0.000	0.042	4.000	0.084	4.000	0.127	4.000	0.169	4.000	0.212	4.000	0.254	4.000	0.297	4.000	0.339
4.000	0.382	4.000	0.424	4.000	0.467	4.000	0.509	4.000	0.552	4.000	0.594	4.000	0.637	4.000	0.679
4.000	0.722	4.000	0.764	4.000	0.807	4.500	0.849	4.500	0.892	4.500	0.934	4.500	0.977	4.500	1.019
4.500	1.062	4.500	1.104	4.500	1.146	4.500	1.189	4.500	1.231	4.500	1.274	4.500	1.316	5.000	1.359
5.000	1.401	5.000	1.444	5.000	1.486	5.000	1.529	5.000	1.571	5.000	1.614	5.000	1.656	5.000	1.699
5.000	1.741	5.000	1.784	5.000	1.826	5.000	1.869	5.000	1.911	5.000	1.954	5.000	1.996	5.000	2.039
5.000	2.081	5.000	2.124	5.000	2.166	5.000	2.209	5.500	2.251	5.500	2.293	5.500	2.336	5.500	2.378
5.500	2.421	5.500	2.463	5.500	2.506	5.500	2.548	5.500	2.591	5.500	2.633	5.500	2.676	5.500	2.718
5.500	2.761	5.500	2.803	5.500	2.846	5.500	2.888	5.500	2.931	5.500	2.973	5.500	3.016	5.500	3.058
5.500	3.101	5.500	3.143	5.500	3.186	5.500	3.228	5.500	3.271	5.500	3.313	5.500	3.355	5.500	3.398
5.500	3.440	5.500	3.483	5.500	3.525	6.000	3.568	6.000	3.610	6.000	3.653	6.000	3.695	6.000	3.738
6.000	3.780	6.000	3.823	6.000	3.865	6.000	3.908	6.000	3.950	6.000	3.993	6.000	4.035	6.000	4.078
6.000	4.120	6.000	4.163	6.000	4.205	6.000	4.248	6.000	4.290	6.000	4.333	6.000	4.375	6.000	4.418
6.000	4.460	6.000	4.502	6.000	4.545	6.000	4.587	6.000	4.630	6.000	4.672	6.000	4.715	6.000	4.757
6.000	4.800	6.000	4.842	6.000	4.885	6.000	4.927	6.000	4.970	6.000	5.012	6.000	5.055	6.000	5.097
6.000	5.140	6.000	5.182	6.000	5.225	6.000	5.267	6.000	5.310	6.500	5.352	6.500	5.395	6.500	5.437
6.500	5.480	6.500	5.522	6.500	5.564	6.500	5.607	6.500	5.649	6.500	5.692	6.500	5.734	6.500	5.777
6.500	5.819	6.500	5.862	6.500	5.904	6.500	5.947	6.500	5.989	6.500	6.032	6.500	6.074	6.500	6.117
6.500	6.159	6.500	6.202	6.500	6.244	6.500	6.287	6.500	6.329	6.500	6.372	6.500	6.414	7.000	6.457
7.000	6.499	7.000	6.542	7.000	6.584	7.000	6.627	7.000	6.669	7.000	6.711	7.000	6.754	7.000	6.796
7.000	6.839	7.000	6.881	7.000	6.924	7.000	6.966	7.000	7.009	7.000	7.051	7.000	7.094	7.000	7.136
7.000	7.179	7.000	7.221	7.000	7.264	7.000	7.306	7.000	7.349	7.000	7.391	7.000	7.434	7.000	7.475
7.000	7.519	7.000	7.561	7.500	7.604	7.500	7.646	7.500	7.689	7.500	7.731	7.500	7.774	7.500	7.815
7.500	7.858	7.500	7.901	7.500	7.943	7.500	7.986	7.500	8.028	7.500	8.071	7.500	8.113	7.500	8.156
7.500	8.198	7.500	8.241	7.500	8.283	7.500	8.326	7.500	8.368	7.500	8.411	7.500	8.453	7.500	8.495
7.500	8.538	7.500	8.581	7.500	8.623	7.500	8.665	7.500	8.708	7.500	8.751	7.500	8.793	7.500	8.835
8.000	8.878	8.000	8.920	8.000	8.963	8.000	9.005	8.000	9.048	8.000	9.090	8.000	9.133	8.000	9.175
8.000	9.218	8.000	9.260	8.000	9.303	8.000	9.345	8.000	9.388	8.000	9.430	8.000	9.473	8.000	9.515
8.000	9.558	8.000	9.600	8.000	9.643	8.000	9.685	8.000	9.728	8.000	9.770	8.000	9.813	8.000	9.855
8.000	9.898	8.000	9.940	8.000	9.983	8.000	10.025	8.000	10.067	8.000	10.110	8.500	10.152	8.500	10.195
8.500	10.237	8.500	10.280	8.500	10.322	8.500	10.365	8.500	10.407	8.500	10.450	8.500	10.492	8.500	10.535
8.500	10.577	8.500	10.620	8.500	10.662	8.500	10.705	8.500	10.747	8.500	10.790	8.500	10.832	8.500	10.875
8.500	10.917	8.500	10.960	8.500	11.002	8.500	11.045	8.500	11.087	8.500	11.129	8.500	11.172	8.500	11.214
8.500	11.257	8.500	11.299	8.500	11.342	8.500	11.384	8.500	11.427	9.000	11.469	9.000	11.512	9.000	11.554
9.000	11.597	9.000	11.639	9.000	11.682	9.000	11.724	9.000	11.767	9.000	11.809	9.000	11.852	9.000	11.894
9.000	11.937	9.000	11.979	9.000	12.022	9.000	12.064	9.000	12.107	9.000	12.149	9.000	12.192	9.000	12.234
9.000	12.276	9.000	12.319	9.000	12.361	9.000	12.404	9.000	12.446	9.000	12.489	9.000	12.531	9.000	12.574
9.000	12.616	9.000	12.659	9.000	12.701	9.000	12.744	9.500	12.786	9.500	12.829	9.500	12.871	9.500	12.914
9.500	12.956	9.500	12.999	9.500	13.041	9.500	13.084	9.500	13.126	9.500	13.169	9.500	13.211	9.500	13.254
9.500	13.296	9.500	13.338	9.500	13.381	9.500	13.423	9.500	13.466	9.500	13.508	9.500	13.551	9.500	13.593
9.500	13.636	9.500	13.678	9.500	13.721	9.500	13.763	9.500	13.806	9.500	13.848	9.500	13.891	10.000	13.933
10.000	13.976	10.000	14.018	10.000	14.061	10.000	14.103	10.000	14.146	10.000	14.188	10.000	14.231	10.000	14.273
10.000	14.316	10.000	14.358	10.000	14.401	10.000	14.443	10.000	14.485	10.000	14.528	10.000	14.570	10.000	14.613
10.000	14.655	10.000	14.698	10.000	14.740	10.000	14.783	10.000	14.825	10.000	14.868	10.000	14.910	10.000	14.953
10.000	14.995	10.000	15.038	10.000	15.080	10.000	15.123	10.000	15.165	10.000	15.208	10.000	15.250	10.000	15.293
10.500	15.335	10.500	15.378	10.500	15.420	10.500	15.463	10.500	15.505	10.500	15.548	10.500	15.590	10.500	15.632
10.500	15.675	10.500	15.717	10.500	15.760	10.500	15.802	10.500	15.845	10.500	15.887	10.500	15.930	10.500	15.972
10.500	16.015	10.500	16.057	10.500	16.100	10.500	16.142	10.500	16.185	10.500	16.227	10.500	16.270	10.500	16.312
10.500	16.355	10.500	16.397	11.000	16.440	11.000	16.482	11.000	16.525	11.000	16.567	11.000	16.610	11.000	16.652
11.000	16.694	11.000	16.737	11.000	16.779	11.000	16.822	11.000	16.864	11.000	16.907	11.000	16.949	11.000	16.992
11.000	17.034	11.000	17.077	11.000	17.119	11.000	17.162	11.000	17.204	11.000	17.247	11.500	17.289	11.500	17.332

11.500	17.374	11.500	17.417	11.500	17.459	11.500	17.502	11.500	17.544	11.500	17.587	11.500	17.629	11.500	17.672
11.500	17.714	11.500	17.757	11.500	17.799	11.500	17.841	11.500	17.884	11.500	17.926	11.500	17.969	11.500	18.011
11.500	18.054	11.500	18.096	11.500	18.139	11.500	18.181	11.500	18.224	11.500	18.266	12.000	18.309	12.000	18.351
12.000	18.394	12.000	18.436	12.000	18.479	12.000	18.521	12.000	18.564	12.000	18.606	12.000	18.649	12.000	18.691
12.000	18.734	12.000	18.776	12.000	18.819	12.000	18.861	12.000	18.903	12.000	18.946	12.000	18.989	12.000	19.031
12.000	19.073	12.500	19.116	12.500	19.158	12.500	19.201	12.500	19.243	12.500	19.286	12.500	19.328	12.500	19.371
12.500	19.413	12.500	19.456	12.500	19.498	12.500	19.541	12.500	19.583	12.500	19.626	12.500	19.668	13.000	19.711
13.000	19.753	13.000	19.796	13.000	19.838	13.000	19.881	13.000	19.923	13.000	19.966	13.000	20.008	13.000	20.050
13.000	20.093	13.000	20.135	13.000	20.178	13.000	20.220	13.000	20.263	13.000	20.305	13.000	20.348	13.000	20.390
13.000	20.433	13.000	20.475	13.000	20.518	13.000	20.560	13.000	20.603	13.000	20.645	13.000	20.688	13.000	20.730
13.500	20.773	13.500	20.815	13.500	20.858	13.500	20.900	13.500	20.943	13.500	20.985	13.500	21.028	13.500	21.070
13.500	21.113	13.500	21.155	13.500	21.197	13.500	21.240	13.500	21.282	13.500	21.325	13.500	21.367	13.500	21.410
13.500	21.452	13.500	21.495	13.500	21.537	14.000	21.580	14.000	21.622	14.000	21.665	14.000	21.707	14.000	21.750
14.000	21.792	14.000	21.835	14.000	21.877	14.000	21.920	14.000	21.962	14.000	22.005	14.000	22.047	14.000	22.090
14.000	22.132	14.000	22.175	14.000	22.217	14.000	22.259	14.000	22.302	14.000	22.344	14.000	22.387	14.000	22.429
14.000	22.472	14.000	22.514	14.000	22.557	14.000	22.599	14.000	22.642	14.000	22.684	14.000	22.727	14.000	22.769
14.500	22.812	14.500	22.854	14.500	22.897	14.500	22.939	14.500	22.982	14.500	23.024	14.500	23.067	14.500	23.109
14.500	23.152	14.500	23.194	14.500	23.237	14.500	23.279	14.500	23.322	14.500	23.364	14.500	23.406	14.500	23.449
14.500	23.491	14.500	23.534	15.000	23.576	15.000	23.619	15.000	23.661	15.000	23.704	15.000	23.746	15.000	23.789
15.000	23.831	15.000	23.874	15.000	23.916	15.000	23.959	15.000	24.001	15.000	24.044	15.000	24.086	15.000	24.129
15.000	24.171	15.000	24.214	15.000	24.256	15.000	24.299	15.500	24.341	15.500	24.384	15.500	24.426	15.500	24.469
15.500	24.511	15.500	24.553	15.500	24.596	15.500	24.638	15.500	24.681	15.500	24.723	15.500	24.766	15.500	24.809
15.500	24.851	15.500	24.893	15.500	24.936	15.500	24.978	15.500	25.021	15.500	25.063	16.000	25.106	16.000	25.149
16.000	25.191	16.000	25.233	16.000	25.276	16.000	25.318	16.000	25.361	16.000	25.403	16.000	25.446	16.000	25.489
16.000	25.531	16.000	25.573	16.500	25.615	16.500	25.658	16.500	25.700	16.500	25.743	16.500	25.785	16.500	25.828
16.500	25.870	16.500	25.913	16.500	25.955	16.500	25.998	16.500	26.040	16.500	26.083	17.000	26.125	17.000	26.168
17.000	26.210	17.000	26.253	17.000	26.295	17.000	26.338	17.000	26.380	17.000	26.423	17.000	26.465	17.000	26.508
17.000	26.550	17.000	26.593	17.000	26.635	17.000	26.677	17.000	26.720	17.000	26.762	17.000	26.805	17.000	26.847
17.000	26.890	17.000	26.932	17.000	26.975	17.000	27.017	17.000	27.060	17.000	27.102	17.500	27.145	17.500	27.187
17.500	27.230	17.500	27.272	17.500	27.315	17.500	27.357	17.500	27.400	17.500	27.442	17.500	27.485	17.500	27.527
17.500	27.570	17.500	27.612	17.500	27.655	17.500	27.697	17.500	27.740	17.500	27.782	17.500	27.824	18.000	27.867
18.000	27.909	18.000	27.952	18.000	27.994	18.000	28.037	18.000	28.079	18.000	28.122	18.000	28.164	18.000	28.207
18.000	28.249	18.000	28.292	18.000	28.334	18.000	28.377	18.000	28.419	18.000	28.462	18.000	28.504	18.000	28.547
18.500	28.589	18.500	28.632	18.500	28.674	18.500	28.717	18.500	28.759	18.500	28.802	18.500	28.844	18.500	28.887
18.500	28.929	18.500	28.971	18.500	29.014	18.500	29.056	18.500	29.099	18.500	29.141	18.500	29.184	18.500	29.226
18.500	29.269	18.500	29.311	18.500	29.354	19.000	29.396	19.000	29.439	19.000	29.481	19.000	29.524	19.000	29.566
19.000	29.609	19.000	29.651	19.000	29.694	19.000	29.736	19.000	29.779	19.000	29.821	19.000	29.864	19.000	29.906
19.000	29.949	19.000	29.991	19.000	30.033	19.000	30.076	19.500	30.118	19.500	30.161	19.500	30.203	19.500	30.246
19.500	30.288	19.500	30.331	19.500	30.373	19.500	30.416	19.500	30.458	19.500	30.501	19.500	30.543	19.500	30.586
19.500	30.628	19.500	30.671	19.500	30.713	20.000	30.756	20.000	30.798	20.000	30.841	20.000	30.883	20.000	30.925
20.000	30.968	20.000	31.011	20.000	31.053	20.000	31.096	20.000	31.138	20.000	31.180	20.000	31.223	20.000	31.265
20.000	31.308	20.000	31.350	20.000	31.393	20.000	31.435	20.000	31.478	20.000	31.520	20.000	31.563	20.000	31.605
20.000	31.648	20.000	31.690	20.000	31.733	20.500	31.775	20.500	31.818	20.500	31.860	20.500	31.903	20.500	31.945
20.500	31.988	20.500	32.030	20.500	32.073	20.500	32.115	20.500	32.158	20.500	32.200	20.500	32.242	20.500	32.285
20.500	32.327	20.500	32.370	20.500	32.412	21.000	32.455	21.000	32.497	21.000	32.540	21.000	32.582	21.000	32.625
21.000	32.667	21.000	32.710	21.000	32.752	21.000	32.795	21.000	32.837	21.000	32.880	21.000	32.922	21.000	32.965
21.000	33.007	21.000	33.050	21.000	33.092	21.500	33.135	21.500	33.177	21.500	33.220	21.500	33.262	21.500	33.305
21.500	33.347	21.500	33.389	21.500	33.432	21.500	33.474	21.500	33.517	21.500	33.559	21.500	33.601	21.500	33.644
21.500	33.687	21.500	33.729	21.500	33.772	21.500	33.814	22.000	33.857	22.000	33.899	22.000	33.941	22.000	33.984
22.000	34.027	22.000	34.069	22.000	34.112	22.000	34.154	22.000	34.197	22.000	34.239	22.000	34.281	22.000	34.324
22.000	34.367	22.000	34.409	22.000	34.452	22.000	34.494	22.000	34.536	22.000	34.579	22.000	34.621	22.000	34.664
22.500	34.706	22.500	34.749	22.500	34.791	22.500	34.834	22.500	34.876	22.500	34.919	22.500	34.961	22.500	35.004
22.500	35.046	22.500	35.089	22.500	35.131	22.500	35.174	22.500	35.216	22.500	35.259	22.500	35.301	22.500	35.344
23.000	35.386	23.000	35.429	23.000	35.471	23.000	35.514	23.000	35.556	23.000	35.598	23.000	35.641	23.000	35.683
23.000	35.726	23.000	35.768	23.000	35.811	23.000	35.853	23.000	35.896	23.000	35.938	23.000	35.981	23.000	36.023
23.500	36.066	23.500	36.108	23.500	36.151	23.500	36.193	23.500	36.236	23.500	36.278	23.500	36.321	23.500	36.363
23.500	36.406	23.500	36.448	23.500	36.491	23.500	36.533	23.500	36.576	23.500	36.618	23.500	36.661	23.500	36.703

23.500	36.745	23.500	36.788	23.500	36.830	23.500	36.873	23.500	36.915	24.000	36.958	24.000	37.000	24.000	37.043
24.000	37.085	24.000	37.128	24.000	37.170	24.000	37.213	24.000	37.255	24.000	37.298	24.000	37.340	24.000	37.383
24.000	37.425	24.000	37.468	24.000	37.510	24.000	37.553	24.000	37.595	24.000	37.638	24.500	37.680	24.500	37.723
24.500	37.765	24.500	37.807	24.500	37.850	24.500	37.892	24.500	37.935	24.500	37.977	24.500	38.020	24.500	38.062
24.500	38.105	24.500	38.147	25.000	38.190	25.000	38.232	25.000	38.275	25.000	38.317	25.000	38.360	25.000	38.402
25.000	38.445	25.000	38.487	25.000	38.530	25.000	38.572	25.000	38.615	25.000	38.657	25.000	38.700	25.000	38.742
25.000	38.785	25.500	38.827	25.500	38.870	25.500	38.912	25.500	38.954	25.500	38.997	25.500	39.039	25.500	39.082
25.500	39.124	25.500	39.167	26.000	39.209	26.000	39.252	26.000	39.294	26.000	39.337	26.000	39.379	26.000	39.422
26.000	39.464	26.000	39.507	26.000	39.549	26.000	39.592	26.000	39.634	26.000	39.677	26.000	39.719	26.000	39.762
26.000	39.804	26.000	39.847	26.000	39.889	26.000	39.932	26.000	39.974	26.000	40.016	26.500	40.059	26.500	40.101
26.500	40.144	26.500	40.186	26.500	40.229	26.500	40.271	26.500	40.314	26.500	40.356	26.500	40.399	26.500	40.441
26.500	40.484	26.500	40.526	27.000	40.569	27.000	40.611	27.000	40.654	27.000	40.696	27.000	40.739	27.000	40.781
27.000	40.824	27.000	40.866	27.000	40.909	27.000	40.951	27.000	40.994	27.500	41.036	27.500	41.079	27.500	41.121
27.500	41.163	27.500	41.206	27.500	41.248	27.500	41.291	27.500	41.333	27.500	41.376	27.500	41.418	27.500	41.461
27.500	41.503	27.500	41.546	27.500	41.588	28.000	41.631	28.000	41.673	28.000	41.716	28.000	41.758	28.000	41.801
28.000	41.843	28.000	41.886	28.000	41.928	28.000	41.971	28.000	42.013	28.500	42.056	28.500	42.098	28.500	42.141
28.500	42.183	28.500	42.226	28.500	42.268	28.500	42.310	28.500	42.353	28.500	42.395	28.500	42.438	28.500	42.480
28.500	42.523	28.500	42.565	29.000	42.608	29.000	42.650	29.000	42.693	29.000	42.735	29.000	42.778	29.000	42.820
29.000	42.863	29.000	42.905	29.000	42.948	29.000	42.990	29.500	43.033	29.500	43.075	29.500	43.118	29.500	43.160
29.500	43.203	30.000	43.245	30.000	43.288	30.000	43.330	30.000	43.372	30.500	43.415	30.500	43.457	30.500	43.500
30.500	43.542	30.500	43.585	30.500	43.627	31.000	43.670	31.000	43.712	31.500	43.755	31.500	43.797	31.500	43.840
31.500	43.882	31.500	43.925	31.500	43.967	31.500	44.010	31.500	44.052	31.500	44.095	32.000	44.137	32.000	44.180
32.000	44.222	32.000	44.265	32.000	44.307	32.000	44.350	32.000	44.392	32.000	44.435	32.000	44.477	32.500	44.519
32.500	44.562	33.000	44.604	33.000	44.647	33.500	44.689	33.500	44.732	33.500	44.774	33.500	44.817	34.000	44.859
34.000	44.902	34.000	44.944	34.000	44.987	34.000	45.029	34.000	45.072	34.500	45.114	34.500	45.157	34.500	45.199
35.000	45.242	35.000	45.284	35.000	45.327	35.000	45.369	35.500	45.412	35.500	45.454	35.500	45.497	35.500	45.539
36.000	45.581	36.000	45.624	36.000	45.666	36.000	45.709	36.000	45.751	36.000	45.794	36.000	45.836	36.000	45.879
36.000	45.921	36.500	45.964	36.500	46.006	36.500	46.049	36.500	46.091	36.500	46.134	37.000	46.176	37.000	46.219
37.000	46.261	37.000	46.304	37.000	46.346	37.500	46.389	37.500	46.431	37.500	46.474	38.000	46.516	38.000	46.559
38.000	46.601	38.000	46.644	38.000	46.686	38.000	46.728	38.000	46.771	38.500	46.813	38.500	46.856	38.500	46.899
38.500	46.941	38.500	46.983	38.500	47.026	38.500	47.068	38.500	47.111	39.000	47.153	39.000	47.196	39.000	47.239
39.000	47.281	39.000	47.323	39.000	47.366	39.500	47.408	39.500	47.451	39.500	47.493	39.500	47.536	40.000	47.579
40.000	47.621	40.000	47.663	40.000	47.706	40.000	47.748	40.500	47.791	40.500	47.833	40.500	47.875	40.500	47.919
40.500	47.960	40.500	48.003	40.500	48.045	41.000	48.088	41.500	48.130	41.500	48.173	41.500	48.215	42.000	48.259
42.000	48.300	42.000	48.343	42.000	48.385	42.000	48.428	42.000	48.470	42.500	48.513	42.500	48.555	42.500	48.599
42.500	48.640	43.000	48.683	43.000	48.725	43.000	48.768	43.000	48.810	43.000	48.853	43.000	48.895	43.000	48.937
43.000	48.980	43.500	49.022	43.500	49.065	43.500	49.107	43.500	49.150	43.500	49.192	44.000	49.235	44.000	49.277
44.000	49.320	44.000	49.362	44.000	49.405	44.000	49.447	44.000	49.490	44.000	49.532	44.000	49.575	44.500	49.617
44.500	49.660	44.500	49.702	44.500	49.745	44.500	49.787	44.500	49.830	44.500	49.872	44.500	49.915	44.500	49.957
44.500	50.000	44.500	50.042	44.500	50.084	45.000	50.127	45.000	50.169	45.000	50.212	45.000	50.254	45.500	50.297
45.500	50.339	45.500	50.382	45.500	50.424	45.500	50.467	45.500	50.509	45.500	50.552	45.500	50.594	46.000	50.637
46.000	50.679	46.000	50.722	46.000	50.764	46.000	50.807	46.000	50.849	46.000	50.892	46.000	50.934	46.000	50.977
46.000	51.019	46.000	51.062	46.000	51.104	46.500	51.146	46.500	51.189	46.500	51.231	46.500	51.274	46.500	51.316
46.500	51.359	46.500	51.401	46.500	51.444	46.500	51.486	47.000	51.529	47.000	51.571	47.000	51.614	47.000	51.656
47.000	51.699	47.000	51.741	47.000	51.784	47.000	51.826	47.000	51.869	47.000	51.911	47.000	51.954	47.500	51.996
47.500	52.039	47.500	52.081	47.500	52.124	47.500	52.166	47.500	52.209	47.500	52.251	47.500	52.293	48.000	52.336
48.000	52.378	48.000	52.421	48.000	52.463	48.000	52.506	48.000	52.548	48.000	52.591	48.000	52.633	48.000	52.676
48.500	52.718	48.500	52.761	48.500	52.803	48.500	52.846	48.500	52.888	48.500	52.931	48.500	52.973	48.500	53.016
49.000	53.058	49.000	53.101	49.000	53.143	49.000	53.186	49.000	53.228	49.000	53.271	49.000	53.313	49.000	53.355
49.000	53.398	49.000	53.440	49.000	53.483	49.500	53.525	49.500	53.568	49.500	53.610	49.500	53.653	50.000	53.695
50.000	53.738	50.000	53.780	50.000	53.823	50.000	53.865	50.000	53.908	50.500	53.950	50.500	53.993	50.500	54.035
50.500	54.078	50.500	54.120	50.500	54.163	50.500	54.205	51.000	54.248	51.000	54.290	51.000	54.333	51.000	54.375
51.000	54.418	51.000	54.460	51.500	54.502	51.500	54.545	51.500	54.587	51.500	54.630	51.500	54.672	52.000	54.715
52.000	54.757	52.000	54.800	52.000	54.842	52.000	54.885	52.000	54.927	52.500	54.970	52.500	55.012	52.500	55.055
53.000	55.097	53.000	55.140	53.000	55.182	53.000	55.225	53.500	55.267	53.500	55.310	53.500	55.352	53.500	55.395
53.500	55.437	54.000	55.480	54.000	55.522	54.500	55.565	55.000	55.607	55.000	55.649	55.000	55.692	55.000	55.734
55.000	55.777	55.500	55.819	55.500	55.862	56.000	55.904	56.000	55.947	57.000	55.989	57.000	56.032	57.000	56.074

57.000	56.117	57.000	56.159	57.000	56.202	57.000	56.244	57.500	56.287	57.500	56.329	57.500	56.372	57.500	56.414
58.000	56.457	58.000	56.499	58.000	56.542	58.000	56.584	58.500	56.627	58.500	56.669	59.000	56.711	59.000	56.754
59.000	56.796	59.000	56.839	59.000	56.881	59.500	56.924	59.500	56.966	59.500	57.009	60.000	57.051	60.000	57.094
60.000	57.136	60.000	57.179	60.500	57.221	60.500	57.264	61.000	57.306	61.000	57.349	61.000	57.391	61.500	57.434
62.000	57.476	62.000	57.519	62.500	57.561	62.500	57.604	63.000	57.646	63.000	57.689	63.000	57.731	63.000	57.774
63.500	57.816	63.500	57.858	63.500	57.901	63.500	57.943	64.000	57.986	64.000	58.028	64.000	58.071	64.000	58.113
64.500	58.156	64.500	58.198	64.500	58.241	64.500	58.283	64.500	58.326	65.000	58.368	65.000	58.411	65.000	58.453
65.000	58.496	65.000	58.538	65.000	58.581	65.000	58.623	65.500	58.666	65.500	58.708	66.000	58.751	66.000	58.793
66.000	58.836	66.000	58.878	66.500	58.920	66.500	58.963	66.500	59.005	66.500	59.048	67.000	59.090	67.000	59.133
67.000	59.175	67.000	59.218	67.000	59.260	67.500	59.303	67.500	59.345	67.500	59.388	67.500	59.430	67.500	59.473
68.000	59.515	68.000	59.558	68.000	59.600	68.500	59.643	69.000	59.685	69.000	59.728	69.000	59.770	69.000	59.813
69.000	59.855	69.000	59.898	69.000	59.940	69.500	59.983	69.500	60.025	69.500	60.067	69.500	60.110	70.000	60.152
70.000	60.195	70.000	60.237	70.500	60.280	70.500	60.322	70.500	60.365	71.000	60.407	71.000	60.450	71.000	60.492
71.000	60.535	71.000	60.577	71.000	60.620	71.000	60.662	71.500	60.705	71.500	60.747	71.500	60.790	71.500	60.832
71.500	60.875	72.000	60.917	72.000	60.960	72.000	61.002	72.000	61.045	72.000	61.087	72.000	61.129	72.000	61.172
72.500	61.214	72.500	61.257	72.500	61.299	72.500	61.342	72.500	61.384	73.000	61.427	73.000	61.469	73.000	61.512
73.000	61.554	73.000	61.597	73.500	61.639	73.500	61.682	73.500	61.724	73.500	61.767	73.500	61.809	73.500	61.852
73.500	61.894	74.000	61.937	74.000	61.979	74.000	62.022	74.000	62.064	74.500	62.107	74.500	62.149	75.000	62.192
75.000	62.234	75.000	62.276	75.000	62.319	75.000	62.361	75.000	62.404	75.000	62.446	75.000	62.489	75.500	62.531
75.500	62.574	76.000	62.616	76.000	62.659	76.000	62.701	76.000	62.744	76.500	62.786	75.500	62.829	76.500	62.871
76.500	62.914	76.500	62.956	77.000	62.999	77.000	63.041	77.000	63.084	77.000	63.126	77.000	63.169	77.500	63.211
77.500	63.254	77.500	63.296	77.500	63.339	77.500	63.381	78.000	63.423	78.000	63.466	78.000	63.508	78.500	63.551
78.500	63.593	78.500	63.636	79.000	63.678	79.000	63.721	79.000	63.763	79.000	63.806	79.000	63.848	79.500	63.891
79.500	63.933	80.000	63.976	80.000	64.018	80.000	64.061	80.000	64.103	80.000	64.145	80.000	64.188	80.500	64.231
80.500	64.273	81.000	64.315	81.000	64.358	81.000	64.401	81.000	64.443	81.000	64.485	81.500	64.528	82.500	64.570
83.000	64.613	83.500	64.655	83.500	64.698	83.500	64.740	84.000	64.783	84.000	64.825	84.000	64.868	85.000	64.910
85.500	64.953	85.500	64.995	85.500	65.038	85.500	65.080	86.000	65.123	86.000	65.165	86.500	65.208	86.500	65.250
86.500	65.293	87.000	65.335	87.000	65.378	87.000	65.420	87.000	65.463	87.000	65.505	87.500	65.548	88.000	65.590
88.000	65.632	89.000	65.675	89.000	65.717	89.000	65.760	89.500	65.802	89.500	65.845	90.000	65.887	90.000	65.930
91.000	65.972	91.000	66.015	91.000	66.057	91.500	66.100	91.500	66.142	91.500	66.185	91.500	66.227	92.000	66.270
92.000	66.312	92.000	66.355	92.500	66.397	92.500	66.440	92.500	66.482	92.500	66.525	92.500	66.567	92.500	66.610
93.000	66.652	93.000	66.694	93.000	66.737	93.500	66.779	93.500	66.822	93.500	66.864	94.000	66.907	94.000	66.949
94.000	66.992	94.000	67.034	94.000	67.077	94.500	67.119	94.500	67.162	95.000	67.204	95.000	67.247	95.000	67.289
95.000	67.332	95.000	67.374	95.500	67.417	95.500	67.459	95.500	67.502	95.500	67.544	95.500	67.587	95.500	67.629
96.000	67.672	96.000	67.714	96.000	67.757	96.000	67.799	96.000	67.841	96.000	67.884	96.000	67.926	96.500	67.969
96.500	68.011	96.500	68.054	96.500	68.096	97.000	68.139	97.000	68.181	97.000	68.224	97.000	68.266	97.500	68.309
97.500	68.351	97.500	68.394	98.000	68.436	98.000	68.479	98.000	68.521	98.000	68.564	98.000	68.606	98.000	68.649
98.000	68.691	98.500	68.734	98.500	68.776	98.500	68.819	99.000	68.861	99.500	68.904	99.500	68.946	100.000	68.989
100.000	69.031	100.500	69.073	101.000	69.116	101.000	69.158	101.500	69.201	101.500	69.243	101.500	69.286	102.000	69.329
102.000	69.371	102.500	69.413	102.500	69.456	102.500	69.498	102.500	69.541	104.000	69.583	104.000	69.626	104.000	69.669
104.500	69.711	104.500	69.753	104.500	69.796	105.000	69.838	105.000	69.881	105.000	69.923	105.000	69.966	105.000	70.008
105.500	70.050	106.000	70.093	106.000	70.135	106.000	70.178	106.500	70.220	107.000	70.263	107.000	70.305	107.000	70.348
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113.000	71.410	113.000	71.452	113.000	71.495	113.000	71.537	113.500	71.580	113.500	71.622	113.500	71.665	113.500	71.707
113.500	71.750	113.500	71.792	114.000	71.835	114.500	71.877	114.500	71.920	115.000	71.962	115.000	72.005	115.000	72.047
115.000	72.090	115.500	72.132	115.500	72.175	115.500	72.217	115.500	72.259	115.500	72.302	116.000	72.344	116.000	72.387
116.000	72.429	116.000	72.472	116.500	72.514	116.500	72.557	117.000	72.599	117.500	72.642	117.500	72.684	118.000	72.727
118.500	72.769	118.500	72.812	118.500	72.854	119.000	72.897	119.000	72.939	119.000	72.982	119.500	73.024	119.500	73.067
119.500	73.109	120.000	73.152	120.000	73.194	120.000	73.237	120.500	73.279	120.500	73.322	120.500	73.364	121.000	73.406
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122.000	73.789	122.500	73.831	122.500	73.874	123.000	73.916	123.000	73.959	123.000	74.001	123.500	74.044	124.000	74.086
124.000	74.129	124.000	74.171	124.000	74.214	124.500	74.256	124.500	74.299	125.000	74.341	125.000	74.384	125.000	74.426
125.500	74.468	125.500	74.511	125.500	74.553	126.000	74.596	126.000	74.639	126.000	74.681	126.500	74.723	126.500	74.765
126.500	74.808	127.000	74.851	127.000	74.893	127.500	74.936	127.500	74.978	128.000	75.021	128.500	75.063	129.000	75.105
129.500	75.148	129.500	75.191	129.500	75.233	130.000	75.276	130.000	75.318	130.000	75.361	130.500	75.403	130.500	75.445

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131.000   75.488 131.000   75.531 131.500   75.573 132.000   75.615 132.000   75.658 132.000   75.700 132.000   75.743 132.500   75.785
132.500   75.828 132.500   75.870 133.000   75.913 133.000   75.955 133.000   75.998 133.500   76.040 134.000   76.083 134.000   76.125
134.000   76.168 134.000   76.210 134.500   76.253 134.500   76.295 134.500   76.338 135.500   76.380 135.500   76.423 135.500   76.465
136.500   76.508 136.500   76.550 137.000   76.593 137.000   76.635 137.500   76.678 137.500   76.720 138.000   76.762 138.000   76.805
138.500   76.847 138.500   76.890 138.500   76.932 138.500   76.975 139.000   77.017 139.000   77.060 139.500   77.102 140.000   77.145
140.000   77.187 140.000   77.230 140.000   77.272 140.000   77.315 140.000   77.357 140.500   77.400 140.500   77.442 140.500   77.485
141.000   77.527 141.000   77.570 141.500   77.612 142.000   77.655 142.000   77.697 142.000   77.740 142.000   77.782 142.000   77.824
142.000   77.867 142.500   77.909 142.500   77.952 142.500   77.994 143.000   78.037 143.500   78.079 143.500   78.122 143.500   78.164
143.500   78.207 144.000   78.249 144.000   78.292 145.000   78.334 145.000   78.377 145.000   78.419 145.500   78.462 145.500   78.504
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154.500   79.906 155.000   79.949 155.000   79.991 155.000   80.033 155.500   80.076 155.500   80.118 156.000   80.161 156.500   80.203
156.500   80.246 156.500   80.288 156.500   80.331 156.500   80.373 157.500   80.416 157.500   80.458 159.000   80.501 158.000   80.543
159.000   80.586 159.000   80.628 159.500   80.671 160.000   80.713 160.000   80.756 160.500   80.798 161.000   80.841 162.000   80.883
162.000   80.926 162.000   80.968 162.000   81.011 162.500   81.053 163.000   81.096 164.000   81.138 164.500   81.180 165.000   81.223
165.500   81.265 165.500   81.308 166.000   81.350 166.000   81.393 166.500   81.435 166.500   81.478 165.500   81.520 166.500   81.563
167.000   81.605 167.000   81.648 167.000   81.690 167.000   81.733 167.500   81.775 167.500   81.818 168.000   81.860 169.000   81.903
169.500   81.945 169.500   81.988 168.500   82.030 168.500   82.073 169.500   82.115 170.000   82.158 170.000   82.200 171.000   82.242
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193.000   84.664 193.000   84.706 194.500   84.749 195.000   84.791 195.500   84.834 197.000   84.876 198.000   84.919 198.500   84.961
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208.000   86.023 208.500   86.066 210.000   86.108 210.500   86.151 211.000   86.193 211.000   86.236 211.000   86.278 211.000   86.321
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214.500   86.703 214.500   86.745 214.500   86.788 214.500   86.830 214.500   86.873 215.000   86.915 215.000   86.958 215.000   87.000
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219.500   87.383 220.000   87.425 220.500   87.468 221.000   87.510 221.000   87.553 221.500   87.595 223.000   87.638 223.000   87.680
223.500   87.723 223.500   87.765 223.500   87.807 224.000   87.850 224.000   87.892 224.500   87.935 224.500   87.977 225.000   88.020
225.500   88.062 225.500   88.105 226.000   88.147 229.000   88.190 229.000   88.232 229.500   88.275 230.500   88.317 231.000   88.360
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238.500   89.082 239.000   89.124 239.000   89.167 239.500   89.209 240.000   89.252 240.000   89.294 240.500   89.337 241.500   89.379
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243.500   89.762 244.000   89.804 244.500   89.847 245.000   89.889 246.000   89.932 246.000   89.974 246.500   90.016 247.000   90.059
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253.000   90.441 254.500   90.484 255.000   90.526 255.000   90.569 256.000   90.611 256.000   90.654 257.000   90.696 257.000   90.739
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262.500   91.121 263.000   91.163 263.000   91.206 263.000   91.248 263.500   91.291 263.500   91.333 263.500   91.376 263.500   91.419
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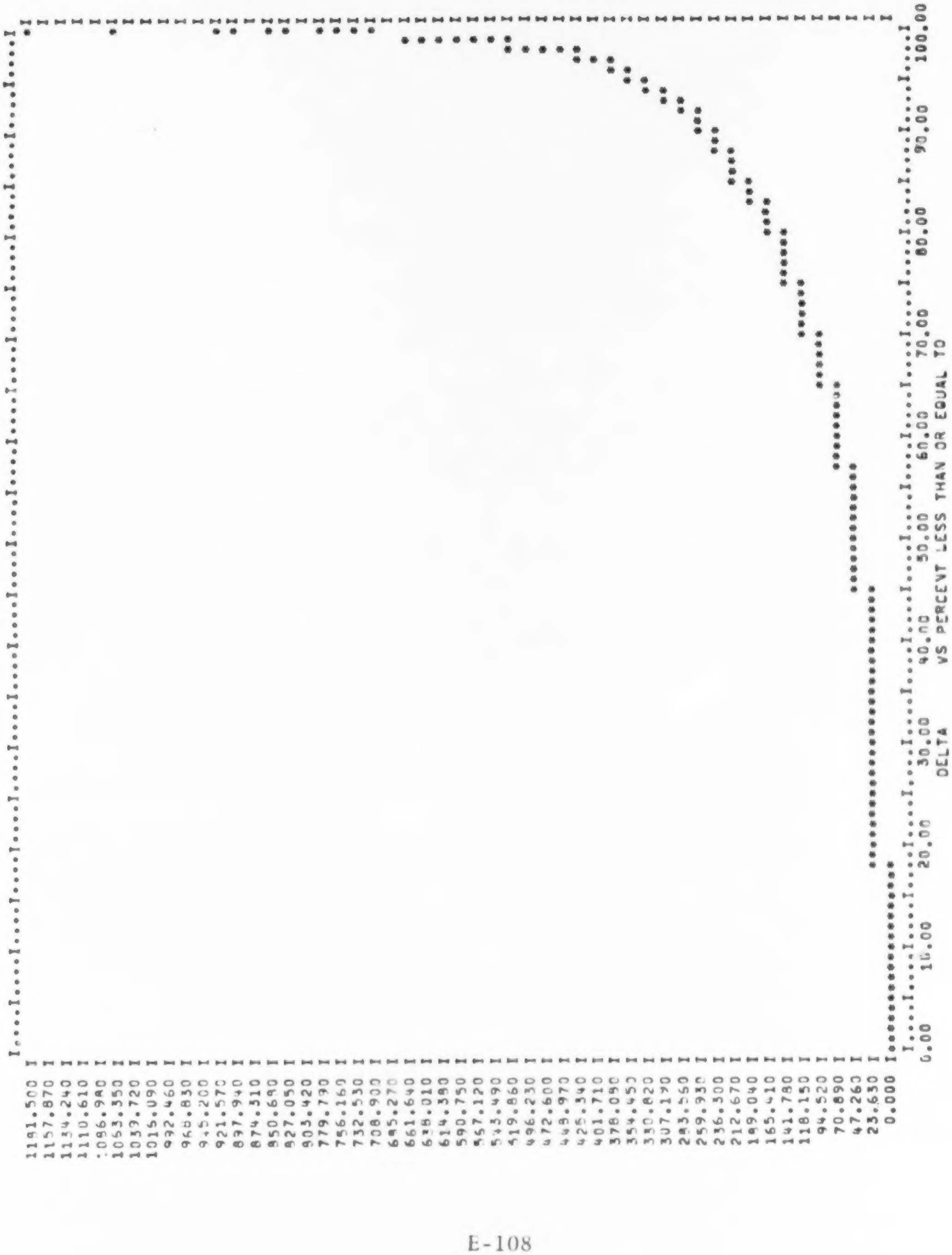
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RETURN PERIOD (IN YEARS) FOR DELTA

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   VALUE  PERIOD    VALUE  PERIOD    VALUE  PERIOD    VALUE  PERIOD    VALUE  PERIOD    VALUE  PERIOD    VALUE  PERIOD    VALUE  PERIOD
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 759.500   2.888 757.000   2.600 741.000   2.363 717.000   2.166 660.500   2.000 660.500   1.857 649.500   1.733 649.000   1.625
 647.500   1.529 644.500   1.444 636.500   1.368 636.000   1.300 516.500   1.238 608.500   1.181 606.000   1.130 579.500   1.083
 569.500   1.040 556.000   1.000 556.000   0.962 554.000   0.929 550.000   0.896 547.000   0.866 540.000   0.839 538.000   0.812
 537.000   0.787 530.000   0.764 523.000   0.742 521.000   0.722 510.500   0.702 509.000   0.684 499.000   0.666 496.500   0.650
 493.000   0.634 486.500   0.619 481.500   0.604 476.500   0.590 473.000   0.577 464.500   0.565 462.000   0.553 459.500   0.541
 459.000   0.530 459.000   0.520 456.500   0.509 451.500   0.500 443.500   0.490 442.000   0.481 438.000   0.472 435.500   0.464
 432.000   0.456 430.000   0.448 422.000   0.440 422.000   0.433 420.000   0.426 419.500   0.419 415.500   0.412 416.000   0.406
 411.500   0.400 410.000   0.393 408.500   0.388 408.500   0.382 408.000   0.376 406.000   0.371 405.000   0.366 405.000   0.361
 402.500   0.356 401.500   0.351 399.000   0.346 399.000   0.342 397.500   0.337 397.000   0.333 394.000   0.329 392.500   0.325
 392.000   0.320 391.500   0.317 398.500   0.313 387.000   0.309 393.000   0.305 390.000   0.302 379.000   0.298 378.500   0.295
 376.000   0.292 375.500   0.288 375.000   0.285 374.000   0.282 373.500   0.279 373.000   0.276 372.000   0.273 371.500   0.270
 370.000   0.268 369.000   0.265 366.500   0.262 365.000   0.260 363.000   0.257 362.000   0.254 360.000   0.252 360.000   0.250
 358.500   0.247 358.500   0.245 351.500   0.242 351.000   0.240 350.000   0.238 346.000   0.236 344.500   0.234 344.500   0.232
 342.500   0.230 340.000   0.228 340.000   0.226 340.000   0.224 339.000   0.222 338.500   0.220 338.500   0.218 338.000   0.216
 338.000   0.214 337.500   0.213 336.500   0.211 335.500   0.209 335.000   0.208 334.500   0.206 334.500   0.204 333.500   0.203
 332.500   0.201 331.500   0.200 331.000   0.198 330.500   0.196 330.500   0.195 330.500   0.194 330.000   0.192 329.000   0.191
 329.000   0.189 328.500   0.188 328.000   0.187 328.000   0.185 325.500   0.184 325.500   0.183 323.000   0.181 322.500   0.180
 322.500   0.179 319.500   0.178 319.000   0.176 319.000   0.175 318.000   0.174 318.000   0.173 317.500   0.172 317.000   0.171
 314.000   0.169 309.500   0.168 309.500   0.167 305.500   0.166 305.000   0.165 304.500   0.164 303.500   0.163 301.000   0.162
 301.000   0.161 299.000   0.160 299.000   0.159 298.500   0.158 297.000   0.157 296.000   0.156 295.500   0.155 294.500   0.154
 294.000   0.153 293.000   0.152 293.000   0.152 292.000   0.151 291.500   0.150 290.500   0.149 290.000   0.148 289.500   0.147
 289.000   0.146 289.000   0.146 289.000   0.145 288.500   0.144 287.500   0.143 287.500   0.142 287.500   0.142 287.000   0.141
 279.000   0.140 277.500   0.139 276.000   0.139 276.000   0.138 275.000   0.137 274.500   0.136 274.500   0.136 273.000   0.135
 272.000   0.134 271.500   0.134 269.500   0.133 268.000   0.132 268.000   0.131 267.000   0.131 266.500   0.130 265.000   0.130
 264.500   0.129 264.500   0.128 263.500   0.128 263.500   0.127 263.500   0.126 263.500   0.126 263.000   0.125 263.000   0.125
 263.000   0.124 262.500   0.123 261.500   0.123 260.500   0.122 260.500   0.122 259.000   0.121 258.500   0.120 257.500   0.120
 257.500   0.119 257.000   0.119 257.000   0.118 257.000   0.118 256.000   0.117 256.000   0.117 255.000   0.116 255.000   0.116
 254.500   0.115 253.000   0.115 253.000   0.114 252.500   0.114 252.000   0.113 251.500   0.113 251.000   0.112 249.500   0.112
 249.000   0.111 248.000   0.111 247.000   0.110 246.500   0.110 246.000   0.109 246.000   0.109 245.000   0.108 244.500   0.108
 244.000   0.107 243.500   0.107 243.000   0.106 243.000   0.106 243.000   0.106 242.500   0.105 242.500   0.105 242.500   0.104
 242.500   0.104 242.000   0.104 241.500   0.103 240.500   0.103 240.000   0.102 240.000   0.102 239.500   0.101 239.000   0.101
 239.000   0.101 238.500   0.100 238.500   0.100 237.500   0.100 237.000   0.099 237.000   0.099 236.000   0.098 236.000   0.098
 236.000   0.098 235.500   0.097 235.500   0.097 235.500   0.097 235.000   0.096 234.500   0.096 233.500   0.095 233.000   0.095
 233.000   0.095 232.500   0.094 231.000   0.094 230.500   0.094 229.500   0.093 229.000   0.093 229.000   0.093 226.000   0.092
 225.500   0.092 225.500   0.092 225.000   0.091 224.500   0.091 224.500   0.091 224.000   0.090 224.000   0.090 222.500   0.090
 223.500   0.089 223.500   0.089 223.000   0.089 223.000   0.089 221.500   0.088 221.000   0.088 221.000   0.088 220.500   0.087
 220.000   0.087 219.500   0.087 219.000   0.086 218.000   0.086 217.000   0.086 217.000   0.086 216.500   0.085 216.500   0.085
 216.000   0.085 216.000   0.084 215.000   0.084 215.000   0.084 215.000   0.084 214.500   0.083 214.500   0.083 214.500   0.083
 214.500   0.083 214.500   0.082 214.000   0.082 213.500   0.082 213.500   0.082 213.500   0.081 212.000   0.081 212.000   0.081
 212.000   0.080 211.000   0.080 211.000   0.080 211.000   0.080 211.000   0.080 211.000   0.079 210.500   0.079 210.000   0.079
 209.500   0.079 209.000   0.078 208.000   0.079 208.000   0.078 207.500   0.078 207.000   0.077 206.500   0.077 206.000   0.077
 205.500   0.077 205.500   0.076 205.000   0.076 204.500   0.076 204.500   0.076 204.000   0.076 202.500   0.075 202.500   0.075
 202.000   0.075 201.500   0.075 200.500   0.074 200.000   0.074 200.000   0.074 199.500   0.074 199.500   0.074 199.500   0.073
 199.000   0.073 198.500   0.073 198.500   0.073 198.000   0.073 197.000   0.072 195.500   0.072 195.000   0.072 194.500   0.072
 193.000   0.072 193.000   0.071 192.500   0.071 192.000   0.071 191.000   0.071 189.500   0.071 189.000   0.070 188.500   0.070
 188.500   0.070 188.500   0.070 188.000   0.070 187.500   0.069 187.500   0.069 187.000   0.069 187.000   0.069 186.500   0.069
 186.500   0.068 186.500   0.068 186.000   0.068 186.000   0.068 186.000   0.068 186.000   0.068 185.500   0.067 185.000   0.067
 185.000   0.067 185.000   0.067 183.500   0.067 183.000   0.067 183.000   0.066 183.000   0.066 182.500   0.066 182.500   0.066
 182.500   0.066 181.500   0.065 181.000   0.065 181.000   0.065 181.000   0.065 180.000   0.065 179.500   0.065 179.500   0.065
 179.000   0.064 178.500   0.064 177.500   0.064 176.500   0.064 176.000   0.064 176.000   0.064 176.000   0.063 174.500   0.063
 174.000   0.063 174.000   0.063 173.500   0.063 173.000   0.063 173.000   0.062 173.000   0.062 172.500   0.062 172.000   0.062
 172.000   0.062 171.000   0.062 171.000   0.062 170.000   0.061 170.000   0.061 169.500   0.061 165.500   0.061 168.500   0.061
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169.500   0.061 169.500   0.061 168.000   0.060 168.000   0.060 167.500   0.060 167.500   0.060 167.000   0.060 167.000   0.060
167.000   0.060 167.000   0.059 166.500   0.059 166.500   0.059 166.500   0.059 166.500   0.059 166.000   0.059 166.000   0.059
165.500   0.058 165.500   0.058 165.000   0.058 164.500   0.058 164.000   0.058 163.000   0.058 162.500   0.058 162.000   0.058
162.000   0.057 162.000   0.057 162.000   0.057 161.000   0.057 160.500   0.057 160.000   0.057 160.000   0.057 159.500   0.057
159.000   0.056 158.000   0.056 158.000   0.056 158.000   0.056 157.500   0.056 157.500   0.056 156.500   0.056 156.500   0.056
156.500   0.055 156.500   0.055 156.500   0.055 156.000   0.055 155.500   0.055 155.500   0.055 155.000   0.055 155.000   0.055
155.000   0.054 154.500   0.054 154.000   0.054 153.500   0.054 153.500   0.054 153.000   0.054 153.000   0.054 152.000   0.054
152.000   0.054 152.000   0.053 151.500   0.053 151.000   0.053 151.000   0.053 151.000   0.053 150.500   0.053 150.500   0.053
150.500   0.053 150.500   0.053 149.500   0.052 149.000   0.052 148.000   0.052 148.000   0.052 147.000   0.052 147.000   0.052
147.000   0.052 147.000   0.052 147.000   0.052 146.500   0.052 146.500   0.051 146.000   0.051 146.000   0.051 145.500   0.051
145.500   0.051 145.500   0.051 145.500   0.051 145.500   0.051 145.000   0.051 145.000   0.050 145.000   0.050 144.000   0.050
144.000   0.050 143.500   0.050 143.500   0.050 143.500   0.050 143.500   0.050 143.000   0.050 142.500   0.050 142.500   0.050
142.500   0.049 142.000   0.049 142.000   0.049 142.000   0.049 142.000   0.049 142.000   0.049 142.000   0.049 141.500   0.049
141.000   0.049 141.000   0.049 140.500   0.048 140.500   0.048 140.500   0.048 140.000   0.048 140.000   0.048 140.000   0.048
140.000   0.048 140.000   0.048 140.000   0.048 139.500   0.048 139.000   0.048 139.000   0.047 138.500   0.047 138.500   0.047
138.500   0.047 138.500   0.047 138.000   0.047 138.000   0.047 137.500   0.047 137.500   0.047 137.000   0.047 137.000   0.047
136.500   0.047 135.500   0.046 135.500   0.046 135.500   0.046 135.500   0.046 134.500   0.046 134.500   0.046 134.500   0.046
134.000   0.046 134.000   0.046 134.000   0.046 134.000   0.046 133.500   0.046 133.000   0.045 133.000   0.045 133.000   0.045
132.500   0.045 132.500   0.045 132.500   0.045 132.000   0.045 132.000   0.045 132.000   0.045 132.000   0.045 131.500   0.045
131.000   0.045 131.000   0.044 130.500   0.044 130.500   0.044 130.000   0.044 130.000   0.044 130.000   0.044 129.500   0.044
129.500   0.044 129.500   0.044 129.000   0.044 128.500   0.044 128.000   0.044 127.500   0.044 127.500   0.043 127.000   0.043
127.000   0.043 126.500   0.043 126.500   0.043 126.500   0.043 126.000   0.043 126.000   0.043 126.000   0.043 125.500   0.043
125.500   0.043 125.500   0.043 125.000   0.043 125.000   0.043 125.000   0.042 124.500   0.042 124.500   0.042 124.000   0.042
124.000   0.042 124.000   0.042 124.000   0.042 123.500   0.042 123.000   0.042 123.000   0.042 123.000   0.042 122.500   0.042
122.500   0.042 122.000   0.042 122.000   0.042 122.000   0.041 121.500   0.041 121.500   0.041 121.500   0.041 121.500   0.041
121.000   0.041 121.000   0.041 121.000   0.041 120.500   0.041 120.500   0.041 120.500   0.041 120.000   0.041 120.000   0.041
120.000   0.041 119.500   0.041 119.500   0.040 119.500   0.040 119.000   0.040 119.000   0.040 119.000   0.040 118.500   0.040
118.500   0.040 118.500   0.040 118.000   0.040 117.500   0.040 117.500   0.040 117.000   0.040 116.500   0.040 116.500   0.040
116.000   0.040 116.000   0.040 116.000   0.039 116.000   0.039 115.500   0.039 115.500   0.039 115.500   0.039 115.500   0.039
115.500   0.039 115.000   0.039 115.000   0.039 115.000   0.039 115.000   0.039 114.500   0.039 114.500   0.039 114.000   0.039
113.500   0.039 113.500   0.039 113.500   0.038 113.500   0.038 113.500   0.038 113.500   0.038 113.000   0.038 113.000   0.038
113.000   0.038 113.000   0.038 112.500   0.038 112.500   0.038 112.500   0.038 112.000   0.038 112.000   0.038 111.500   0.038
111.500   0.038 111.500   0.038 111.000   0.038 110.500   0.038 110.500   0.037 110.500   0.037 110.500   0.037 110.000   0.037
109.500   0.037 109.500   0.037 109.500   0.037 109.000   0.037 109.000   0.037 108.500   0.037 107.500   0.037 107.500   0.037
107.500   0.037 107.000   0.037 107.000   0.037 107.000   0.037 107.000   0.037 106.500   0.037 106.000   0.036 106.000   0.036
106.000   0.036 105.500   0.036 105.000   0.036 105.000   0.036 105.000   0.036 105.000   0.036 105.000   0.036 104.500   0.036
104.500   0.036 104.500   0.036 104.000   0.036 104.000   0.036 104.000   0.036 102.500   0.036 102.500   0.036 102.500   0.036
102.500   0.036 102.000   0.036 102.000   0.035 101.500   0.035 101.500   0.035 101.500   0.035 101.000   0.035 101.000   0.035
100.500   0.035 100.000   0.035 100.000   0.035  99.500   0.035  99.500   0.035  99.000   0.035  98.500   0.035  98.500   0.035
 98.500   0.035  98.000   0.035  98.000   0.035  98.000   0.035  98.000   0.035  98.000   0.035  98.000   0.034  98.000   0.034
 97.500   0.034  97.500   0.034  97.500   0.034  97.000   0.034  97.000   0.034  97.000   0.034  97.000   0.034  96.500   0.034
 96.500   0.034  96.500   0.034  96.500   0.034  96.000   0.034  96.000   0.034  96.000   0.034  96.000   0.034  96.000   0.034
 96.000   0.034  96.000   0.034  95.500   0.034  95.500   0.034  95.500   0.033  95.500   0.033  95.500   0.033  95.500   0.033
 95.000   0.033  95.000   0.033  95.000   0.033  95.000   0.033  95.000   0.033  94.500   0.033  94.500   0.033  94.000   0.033
 94.000   0.033  94.000   0.033  94.000   0.033  94.000   0.033  93.500   0.033  93.500   0.033  93.500   0.033  93.000   0.033
 93.000   0.033  93.000   0.033  92.500   0.033  92.500   0.032  92.500   0.032  92.500   0.032  92.500   0.032  92.500   0.032
 92.000   0.032  92.000   0.032  92.000   0.032  91.500   0.032  91.500   0.032  91.500   0.032  91.500   0.032  91.000   0.032
 91.000   0.032  91.000   0.032  90.000   0.032  90.000   0.032  89.500   0.032  89.500   0.032  89.000   0.032  89.000   0.032
 89.000   0.032  88.000   0.032  88.000   0.032  87.500   0.032  87.000   0.031  87.000   0.031  87.000   0.031  87.000   0.031
 87.000   0.031  86.500   0.031  86.500   0.031  86.500   0.031  86.000   0.031  86.000   0.031  85.500   0.031  85.500   0.031
 85.500   0.031  85.500   0.031  85.000   0.031  84.000   0.031  84.000   0.031  84.000   0.031  83.500   0.031  83.500   0.031
 83.500   0.031  83.000   0.031  82.500   0.031  81.500   0.031  81.000   0.031  81.000   0.031  81.000   0.030  81.400   0.030
 81.000   0.030  80.500   0.030  80.500   0.030  80.000   0.030  80.000   0.030  80.000   0.030  80.000   0.030  80.000   0.030
 80.000   0.030  79.500   0.030  79.500   0.030  79.000   0.030  79.000   0.030  79.000   0.030  79.000   0.030  79.000   0.030
 78.500   0.030  78.500   0.030  78.500   0.030  78.000   0.030  78.000   0.030  78.000   0.030  77.500   0.030  77.500   0.030
 77.500   0.030  77.500   0.030  77.500   0.029  77.000   0.029  77.000   0.029  77.000   0.029  77.000   0.029  77.000   0.029
 76.500   0.029  76.500   0.029  76.500   0.029  76.500   0.029  76.500   0.029  76.000   0.029  76.000   0.029  76.000   0.029
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76.000   0.029  75.500   0.029  75.500   0.029  75.000   0.029  75.000   0.029  75.000   0.029  75.000   0.029  75.000   0.029
75.000   0.029  75.000   0.029  75.000   0.029  74.500   0.029  74.500   0.029  74.000   0.029  74.000   0.029  74.000   0.029
74.000   0.028  73.500   0.028  73.500   0.028  73.500   0.028  73.500   0.028  73.500   0.029  73.500   0.028  73.500   0.028
73.000   0.028  73.000   0.028  73.000   0.028  73.000   0.028  73.000   0.028  72.500   0.028  72.500   0.028  72.500   0.028
72.500   0.028  72.500   0.028  72.000   0.028  72.000   0.028  72.000   0.028  72.000   0.028  72.000   0.028  72.000   0.028
72.000   0.028  71.500   0.028  71.500   0.028  71.500   0.028  71.500   0.028  71.500   0.028  71.000   0.028  71.000   0.028
71.000   0.027  71.000   0.027  71.000   0.027  71.000   0.027  71.000   0.027  70.500   0.027  70.500   0.027  70.500   0.027
70.000   0.027  70.000   0.027  70.000   0.027  69.500   0.027  69.500   0.027  69.500   0.027  69.500   0.027  69.000   0.027
69.000   0.027  69.000   0.027  69.000   0.027  69.000   0.027  69.000   0.027  69.000   0.027  68.500   0.027  68.000   0.027
68.000   0.027  68.000   0.027  67.500   0.027  67.500   0.027  67.500   0.027  67.500   0.027  67.500   0.027  67.000   0.027
67.000   0.027  67.000   0.027  67.000   0.026  67.000   0.026  66.500   0.026  66.500   0.026  66.500   0.026  66.500   0.026
66.000   0.026  66.000   0.026  66.000   0.026  66.000   0.026  65.500   0.025  65.500   0.026  65.000   0.026  65.000   0.026
65.000   0.026  65.000   0.026  65.000   0.026  65.000   0.026  65.000   0.026  64.500   0.026  64.500   0.026  64.500   0.026
64.500   0.026  64.500   0.026  64.000   0.026  64.000   0.026  64.000   0.026  64.000   0.026  63.500   0.026  63.500   0.026
63.500   0.026  63.500   0.026  63.000   0.026  63.000   0.026  63.000   0.026  63.000   0.026  62.500   0.026  62.500   0.026
62.000   0.025  62.000   0.025  61.500   0.025  61.000   0.025  61.000   0.025  61.000   0.025  60.500   0.025  60.500   0.025
60.000   0.025  60.000   0.025  60.000   0.025  60.000   0.025  59.500   0.025  59.500   0.025  59.500   0.025  59.000   0.025
59.000   0.025  59.000   0.025  59.000   0.025  59.000   0.025  58.500   0.025  58.500   0.025  58.000   0.025  58.000   0.025
58.000   0.025  58.000   0.025  57.500   0.025  57.500   0.025  57.500   0.025  57.500   0.025  57.000   0.025  57.000   0.025
57.000   0.025  57.000   0.025  57.000   0.025  57.000   0.025  57.000   0.025  56.000   0.025  56.000   0.025  55.500   0.025
55.500   0.024  55.000   0.024  55.000   0.024  55.000   0.024  55.000   0.024  55.000   0.024  54.500   0.024  54.000   0.024
54.000   0.024  53.500   0.024  53.500   0.024  53.500   0.024  53.500   0.024  53.500   0.024  53.000   0.024  53.000   0.024
53.000   0.024  53.000   0.024  52.500   0.024  52.500   0.024  52.500   0.024  52.000   0.024  52.000   0.024  52.000   0.024
52.000   0.024  52.000   0.024  52.000   0.024  51.500   0.024  51.500   0.024  51.500   0.024  51.500   0.024  51.500   0.024
51.000   0.024  51.000   0.024  51.000   0.024  51.000   0.024  51.000   0.024  51.000   0.024  50.500   0.024  50.500   0.024
50.500   0.024  50.500   0.024  50.500   0.024  50.500   0.023  50.500   0.023  50.000   0.023  50.000   0.023  50.000   0.023
50.000   0.023  50.000   0.023  50.000   0.023  49.500   0.023  49.500   0.023  49.500   0.023  49.500   0.023  49.000   0.023
49.000   0.023  49.000   0.023  49.000   0.023  49.000   0.023  49.000   0.023  49.000   0.023  49.000   0.023  49.000   0.023
49.000   0.023  49.000   0.023  48.500   0.023  48.500   0.023  48.500   0.023  48.500   0.023  48.500   0.023  48.500   0.023
49.500   0.023  48.500   0.023  48.000   0.023  48.000   0.023  48.000   0.023  48.000   0.023  48.000   0.023  48.000   0.023
48.000   0.023  48.000   0.023  48.000   0.023  47.500   0.023  47.500   0.023  47.500   0.023  47.500   0.023  47.500   0.023
47.500   0.023  47.500   0.023  47.500   0.022  47.000   0.022  47.000   0.022  47.000   0.022  47.000   0.022  47.000   0.022
47.000   0.022  47.000   0.022  47.000   0.022  47.000   0.022  47.000   0.022  47.000   0.022  46.500   0.022  46.500   0.022
46.500   0.022  46.500   0.022  46.500   0.022  46.500   0.022  46.500   0.022  46.500   0.022  46.500   0.022  46.000   0.022
46.000   0.022  46.000   0.022  46.000   0.022  46.000   0.022  46.000   0.022  46.000   0.022  46.000   0.022  46.000   0.022
46.000   0.022  46.000   0.022  46.000   0.022  45.500   0.022  45.500   0.022  45.500   0.022  45.500   0.022  45.500   0.022
45.500   0.022  45.500   0.022  45.500   0.022  45.000   0.022  45.000   0.022  45.000   0.022  45.000   0.022  44.500   0.022
44.500   0.022  44.500   0.022  44.500   0.022  44.500   0.022  44.500   0.022  44.500   0.021  44.500   0.021  44.500   0.021
44.500   0.021  44.500   0.021  44.500   0.021  44.000   0.021  44.000   0.021  44.000   0.021  44.000   0.021  44.000   0.021
44.000   0.021  44.000   0.021  44.000   0.021  44.000   0.021  43.500   0.021  43.500   0.021  43.500   0.021  43.500   0.021
43.500   0.021  43.000   0.021  43.000   0.021  43.000   0.021  43.000   0.021  43.000   0.021  43.000   0.021  43.000   0.021
43.000   0.021  42.500   0.021  42.500   0.021  42.500   0.021  42.500   0.021  42.000   0.021  42.000   0.021  42.000   0.021
42.000   0.021  42.000   0.021  42.000   0.021  41.500   0.021  41.500   0.021  41.500   0.021  41.000   0.021  40.500   0.021
40.500   0.021  40.500   0.021  40.500   0.021  40.500   0.021  40.500   0.021  40.500   0.021  40.000   0.021  40.000   0.021
40.000   0.021  40.000   0.021  40.000   0.021  39.500   0.021  39.500   0.021  39.500   0.021  39.500   0.020  39.000   0.020
39.000   0.020  39.000   0.020  39.000   0.020  39.000   0.020  39.000   0.020  38.500   0.020  38.500   0.020  38.500   0.020
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38.000   0.020  38.000   0.020  38.000   0.020  38.000   0.020  37.500   0.020  37.500   0.020  37.500   0.020  37.000   0.020
37.000   0.020  37.000   0.020  37.000   0.020  37.000   0.020  36.500   0.020  36.500   0.020  36.500   0.020  36.500   0.020
36.500   0.020  36.000   0.020  36.000   0.020  36.000   0.020  36.000   0.020  36.000   0.020  36.000   0.020  36.000   0.020
36.000   0.020  36.000   0.020  35.500   0.020  35.500   0.020  35.500   0.020  35.500   0.020  35.000   0.020  35.000   0.020
35.000   0.020  35.000   0.020  34.500   0.020  34.500   0.020  34.500   0.020  34.000   0.020  34.000   0.020  34.000   0.020
34.000   0.020  34.000   0.020  34.000   0.020  33.500   0.020  33.500   0.019  33.500   0.019  33.500   0.019  33.000   0.019
33.000   0.019  32.500   0.019  32.500   0.019  32.000   0.019  32.000   0.019  32.000   0.019  32.000   0.019  32.000   0.019
32.000   0.019  32.000   0.019  32.000   0.019  32.000   0.019  31.500   0.019  31.500   0.019  31.500   0.019  31.500   0.019
31.500   0.019  31.500   0.019  31.500   0.019  31.500   0.019  31.500   0.019  31.000   0.019  31.000   0.019  30.500   0.019
30.500   0.019  30.500   0.019  30.500   0.019  30.500   0.019  30.500   0.019  30.000   0.019  30.000   0.019  30.000   0.019
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29.000   0.019  29.000   0.019  29.000   0.019  29.000   0.019  29.000   0.019  29.000   0.019  29.000   0.019  29.000   0.019
28.500   0.019  28.500   0.019  28.500   0.019  28.500   0.019  28.500   0.019  28.500   0.019  28.500   0.019  28.500   0.019
28.500   0.019  28.500   0.019  28.500   0.019  28.500   0.019  28.500   0.019  28.000   0.019  28.000   0.019  28.000   0.019
28.000   0.018  28.000   0.018  28.000   0.018  28.000   0.018  28.000   0.018  28.000   0.018  28.000   0.018  27.500   0.018
27.500   0.018  27.500   0.018  27.500   0.018  27.500   0.018  27.500   0.018  27.500   0.018  27.500   0.018  27.500   0.018
27.500   0.018  27.500   0.018  27.500   0.018  27.500   0.018  27.500   0.018  27.000   0.018  27.000   0.018  27.000   0.018
27.000   0.018  27.000   0.018  27.000   0.018  27.000   0.018  27.000   0.018  27.000   0.018  27.000   0.018  27.000   0.018
26.500   0.018  26.500   0.018  26.500   0.018  26.500   0.018  26.500   0.018  26.500   0.018  26.500   0.018  26.500   0.018
26.500   0.018  26.500   0.018  26.500   0.018  26.500   0.018  26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018
26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018
26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018  26.000   0.018
25.500   0.018  25.500   0.018  25.500   0.018  25.500   0.018  25.500   0.018  25.500   0.018  25.500   0.018  25.500   0.018
25.500   0.018  25.000   0.018  25.000   0.018  25.000   0.018  25.000   0.017  25.000   0.017  25.000   0.017  25.000   0.017
25.000   0.017  25.000   0.017  25.000   0.017  25.000   0.017  25.000   0.017  25.000   0.017  25.000   0.017  25.000   0.017
24.500   0.017  24.500   0.017  24.500   0.017  24.500   0.017  24.500   0.017  24.500   0.017  24.500   0.017  24.500   0.017
24.500   0.017  24.500   0.017  24.500   0.017  24.500   0.017  24.000   0.017  24.000   0.017  24.000   0.017  24.000   0.017
24.000   0.017  24.000   0.017  24.000   0.017  24.000   0.017  24.000   0.017  24.000   0.017  24.000   0.017  24.000   0.017
24.000   0.017  24.000   0.017  24.000   0.017  24.000   0.017  24.000   0.017  23.500   0.017  23.500   0.017  23.500   0.017
23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017
23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017  23.500   0.017
23.500   0.017  23.500   0.017  23.000   0.017  23.000   0.017  23.000   0.017  23.000   0.017  23.000   0.017  23.000   0.017
23.000   0.017  23.000   0.017  23.000   0.017  23.000   0.017  23.000   0.017  23.000   0.017  23.000   0.017  23.000   0.017
23.000   0.017  23.000   0.017  22.500   0.017  22.500   0.017  22.500   0.017  22.500   0.017  22.500   0.017  22.500   0.017
22.500   0.017  22.500   0.016  22.500   0.016  22.500   0.016  22.500   0.016  22.500   0.016  22.500   0.016  22.500   0.016
22.500   0.016  22.500   0.016  22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016
22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016
22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016  22.000   0.016  21.500   0.016  21.500   0.016  21.500   0.016
21.500   0.016  21.500   0.016  21.500   0.016  21.500   0.016  21.500   0.016  21.500   0.016  21.500   0.016  21.500   0.016
21.500   0.016  21.500   0.016  21.500   0.016  21.500   0.016  21.500   0.016  21.500   0.016  21.000   0.016  21.000   0.016
21.000   0.016  21.000   0.016  21.000   0.016  21.000   0.016  21.000   0.016  21.000   0.016  21.000   0.016  21.000   0.016
21.000   0.016  21.000   0.016  21.000   0.016  21.000   0.016  21.000   0.016  21.000   0.016  21.000   0.016  20.500   0.016
20.500   0.016  20.500   0.016  20.500   0.016  20.500   0.016  20.500   0.016  20.500   0.016  20.500   0.016  20.500   0.016
20.500   0.016  20.500   0.016  20.500   0.016  20.500   0.016  20.500   0.016  20.500   0.016  20.500   0.016  20.000   0.016
20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016
20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016  20.000   0.016
20.000   0.016  20.000   0.015  20.000   0.015  20.000   0.015  20.000   0.015  20.000   0.015  20.000   0.015  19.500   0.015
19.500   0.015  19.500   0.015  19.500   0.015  19.500   0.015  19.500   0.015  19.500   0.015  19.500   0.015  19.500   0.015
19.500   0.015  19.500   0.015  19.500   0.015  19.500   0.015  19.500   0.015  19.500   0.015  19.000   0.015  19.000   0.015
19.000   0.015  19.000   0.015  19.000   0.015  19.000   0.015  19.000   0.015  19.000   0.015  19.000   0.015  19.000   0.015
19.000   0.015  19.000   0.015  19.000   0.015  19.000   0.015  19.000   0.015  19.000   0.015  19.000   0.015  18.500   0.015
18.500   0.015  18.500   0.015  18.500   0.015  18.500   0.015  18.500   0.015  18.500   0.015  18.500   0.015  18.500   0.015
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18.500   0.015  18.500   0.015  18.000   0.015  18.000   0.015  18.000   0.015  18.000   0.015  18.000   0.015  18.000   0.015
18.000   0.015  18.000   0.015  18.000   0.015  18.000   0.015  18.000   0.015  18.000   0.015  18.000   0.015  18.000   0.015
18.000   0.015  18.000   0.015  18.000   0.015  17.500   0.015  17.500   0.015  17.500   0.015  17.500   0.015  17.500   0.015
17.500   0.015  17.500   0.015  17.500   0.015  17.500   0.015  17.500   0.015  17.500   0.015  17.500   0.015  17.500   0.015
17.500   0.015  17.500   0.015  17.500   0.015  17.500   0.015  17.000   0.015  17.000   0.015  17.000   0.015  17.000   0.015
17.000   0.015  17.000   0.015  17.000   0.015  17.000   0.015  17.000   0.015  17.000   0.015  17.000   0.015  17.000   0.015
17.000   0.015  17.000   0.015  17.000   0.015  17.000   0.015  17.000   0.015  17.000   0.014  17.000   0.014  17.000   0.014
17.000   0.014  17.000   0.014  17.000   0.014  17.000   0.014  16.500   0.014  16.500   0.014  16.500   0.014  16.500   0.014
16.500   0.014  16.500   0.014  16.500   0.014  16.500   0.014  16.500   0.014  16.500   0.014  16.500   0.014  16.500   0.014
16.000   0.014  16.000   0.014  16.000   0.014  16.000   0.014  16.000   0.014  16.000   0.014  16.000   0.014  16.000   0.014
16.000   0.014  16.000   0.014  16.000   0.014  16.000   0.014  15.500   0.014  15.500   0.014  15.500   0.014  15.500   0.014
15.500   0.014  15.500   0.014  15.500   0.014  15.500   0.014  15.500   0.014  15.500   0.014  15.500   0.014  15.500   0.014
15.500   0.014  15.500   0.014  15.500   0.014  15.500   0.014  15.500   0.014  15.500   0.014  15.000   0.014  15.000   0.014
15.000   0.014  15.000   0.014  15.000   0.014  15.000   0.014  15.000   0.014  15.000   0.014  15.000   0.014  15.000   0.014
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14.500   0.014  14.500   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014
14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014
14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014
14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  14.000   0.014  13.500   0.014
13.500   0.014  13.500   0.014  13.500   0.014  13.500   0.014  13.500   0.014  13.500   0.014  13.500   0.014  13.500   0.014
13.500   0.014  13.500   0.013  13.500   0.013  13.500   0.013  13.500   0.013  13.500   0.013  13.500   0.013  13.500   0.013
13.500   0.013  13.500   0.013  13.000   0.013  13.000   0.013  13.000   0.013  13.000   0.013  13.000   0.013  13.000   0.013
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13.000   0.013  13.000   0.013  13.000   0.013  12.500   0.013  12.500   0.013  12.500   0.013  12.500   0.013  12.500   0.013
12.500   0.013  12.500   0.013  12.500   0.013  12.500   0.013  12.500   0.013  12.500   0.013  12.500   0.013  12.500   0.013
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12.000   0.013  12.000   0.013  12.000   0.013  12.000   0.013  12.000   0.013  12.000   0.013  12.000   0.013  12.000   0.013
12.000   0.013  12.000   0.013  12.000   0.013  12.000   0.013  11.500   0.013  11.500   0.013  11.500   0.013  11.500   0.013
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 9.000   0.012   9.000   0.012   9.000   0.012   9.000   0.012   9.000   0.012   8.500   0.012   8.500   0.012   8.500   0.012
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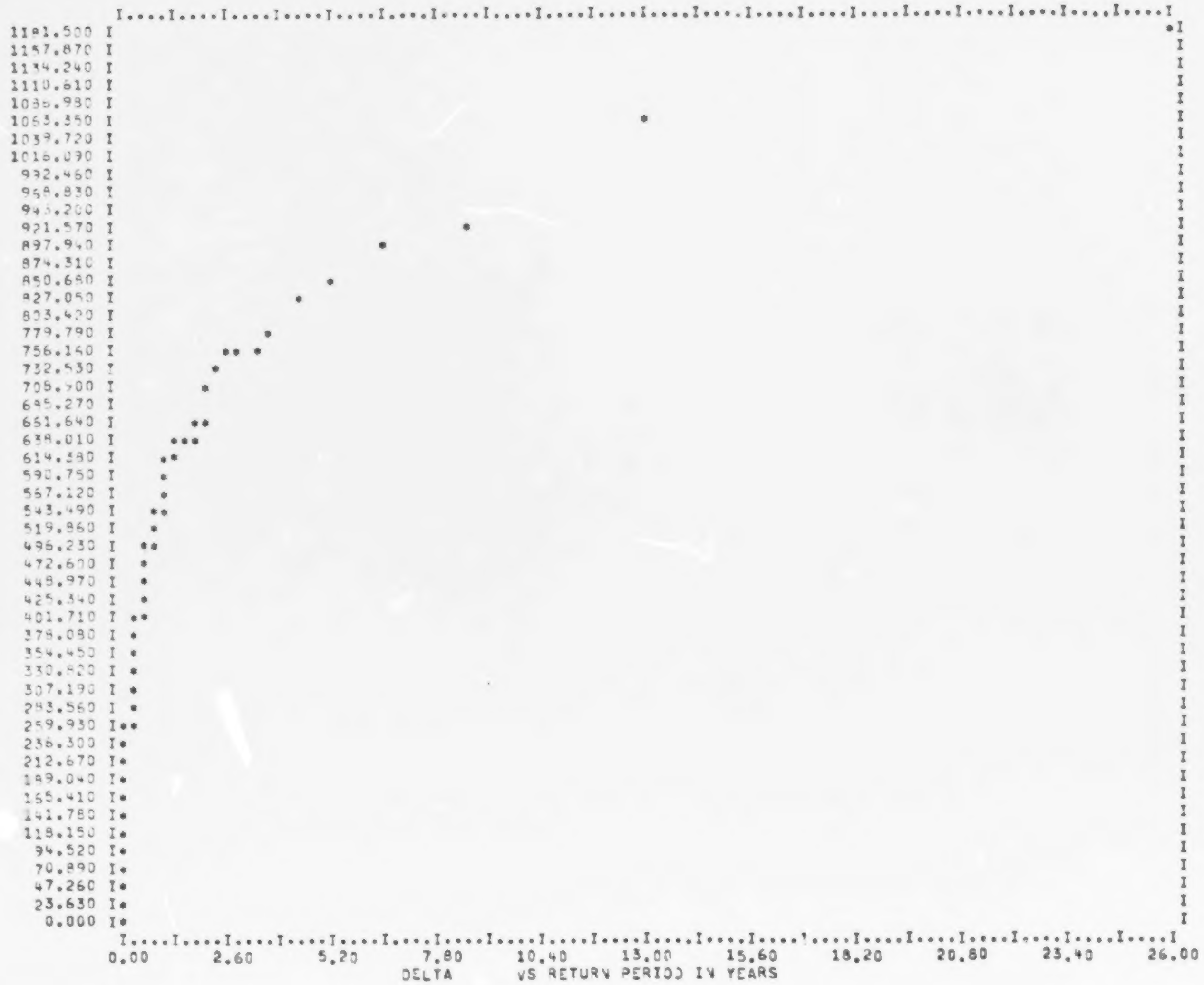
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DELTA VS RETURN PERIOD IN YEARS

APPENDIX J

GLOSSARY

Abatement - The lessening of pollution effects.

Access Time - Time required by computer to locate a word in core memory and transfer the word to a register.

Acre Foot - A unit for measuring the volume of water. It is equal to the amount of water needed to cover one acre of land with water one foot deep.

The Act - Public Law 92-500. "Federal Water Pollution Control Act Amendments of 1972."

Address - Name or number which identifies a particular storage location in the computer.

Advanced Waste Treatment - A further degree of treatment of wastewater, over and above so-called secondary treatment, in order to further purify these effluent waters by the removal of additional amounts or types of pollutants, or their modification into non-polluting forms.

Advection - The hydraulic mechanism by which water quality constituents are transported in the direction of the water flow.

Aerated Lagoon - A natural or artificial wastewater treatment lagoon (generally from 4 to 12 feet deep) in which mechanical or diffused-air aeration is used to supplement the oxygen supply.

Aeration - The act of exposing to the action of air, such as, to mix or charge with air.

Aerosol - A suspension of fine solid or liquid particles in air or gas.

Agricultural Land - Land in farms regularly used for agricultural production. The term includes all land devoted to crop or livestock enterprises; for example, the farmstead lands, drainage and irrigation ditches, water supply, cropland, and grazing land of every kind in farms.

Agronomic Practices - The soil and crop activities employed in the production of farm crops, such as selecting seed, seedbed preparation, fertilizing, liming, manuring, seeding, cultivation, harvesting, curing, crop sequence, crop rotations, cover crops, stripcropping, pasture development, etc.

Air Flotation Treatment - In this system, air bubbles are formed by introducing the gas phase directly into the liquid phase through a revolving impeller or through diffusers. Flotation is used to remove suspended matter and to concentrate biological sludges. Aeration alone for a short period is not particularly effective in bringing about the flotation of solids.

Algae - Any of numerous chlorophyll-containing plants of the phylum thallophyta that grow in either sea water or fresh water; seaweeds and pond scum are algae.

Algorithm - A rule or procedure for solving a logical or mathematical problem, frequently as incorporated into computer programs.

Alkaline - Having the qualities of a base; i.e., a pH above 7.0.

Alluvial - Of or pertaining to alluvium.

Alluvium - Clay, silt, sand, gravel, or other rock materials transported by flowing water and deposited in comparatively recent geologic time as sorted or semi-sorted sediments in riverbeds, estuaries, floodplains, and in fans at the base of mountain slopes.

Ambient - Completely surrounding or encompassing.

Amenable Industrial Wastes - Industrial wastewaters which contain no concentrations of substances which adversely affect sewer systems or inhibit the operation of sewage treatment processes which depend on biological reactions.

Ammonia-Nitrogen (NH_4) - A form of nitrogen which is an essential nutrient to plants (can cause algal blooms if all nutrients are present in sufficient quantities). A product of natural decomposition of fecal matter, urea and other animal protein.

Ammonification - The biochemical process whereby ammonia-nitrogen is released from nitrogen-containing organic compounds.

Ammonium Fixation - The adsorption or absorption of ammonium ions by the mineral or organic fractions of the soil in a manner that they are relatively unexchangeable by the usual methods of cation exchange.

Amortization Period - The period of time over which the cost of a capital item is amortized.

Analog - The representation of a numerical quantity by some physical variable; e.g., translation, rotation, voltage or resistance.

Analysis of Variance - A statistical technique which analyzes the variance which can be attributed to each of several factors which were varied singly or in combination.

Angle of Repose - The angle which the sloping face of a bank of loose earth, or gravel, or other material makes with the horizontal.

Actual Cost - Total annual expense of operating a treatment plant, including capital charges, fuel, power, chemicals, supplies and maintenance materials, taxes, insurance, and any other costs of operation.

Antecedent Conditions - Initial conditions in catchment as determined from hydrologic events prior to storm.

Antecedent Moisture Conditions (AMC) - The degree of wetness of a watershed at the beginning of a storm.

Antecedent Precipitation Index (API) - An indicator of the amount of water (in inches) present in the soil at any given time. The calculation of the API is based on the assumption that, during time periods of no precipitation, the soil moisture decreases logarithmically with time.

Application Rate - The rate at which a liquid is dosed to the land (in./hr, ft/yr, etc.).

Aquifer - Any geological formation that contains water, especially one that supplies wells and springs.

Area Rainfall Distribution Factor - The ratio of the rainfall in a selected area to that measured at a reference rainfall gage.

Artesian - The occurrence of groundwater under sufficient pressure to rise above the upper surface of the aquifer.

Artesian Aquifer - An aquifer overlain by a confining bed and containing water under artesian conditions.

Artificial Recharge - The addition of water to the groundwater reservoir by activities of man, such as irrigation or induced infiltration from streams, wells, or spreading basins.

ASCII Code - American Standard Code for Information Interchange; a special eight channel paper tape code developed to facilitate data transmission between machines manufactured by different companies.

Asphalt Concrete - A paving material consisting of aggregate bound with asphalt, made by heating both materials to around 300°F, followed by mixing, delivering, spreading, and compacting while still hot.

Attenuation - The reduction of the magnitude of an event, as the reduction and spreading out of the impact of storm effects.

Autoanalyzer - Copywritten term referring to equipment which automates chemical tests on samples.

Available Nutrient - That portion of any element or compound in the soil that readily can be absorbed and assimilated by growing plants.

Average Cleansing Efficiency - The percent of deposited solids removed from a given length of sewer.

Backfill - That material that is used to cover a sewer in a trench extending from the sewer or select fill to the ground surface.

Background - A description of pollutant levels arising from natural sources, and not because of man's immediate activities.

Backwater Curve - The longitudinal shape of the water surface in a stream or open conduit where such water surface is raised above its normal level by a natural or artificial constriction or a change in grade.

Backwater Gate - A gate installed at the end of a drain or outlet pipe to prevent the backward flow of water or wastewater. Generally used on sewer outlets into streams to prevent backward flow during times of flood or high tide. Also called a tide gate.

Bar Screen - A screen composed of parallel bars, either vertical or inclined, placed in a waterway to catch debris, and from which the screenings may be raked. (Also called a rack).

Base Flow - Stream discharge derived from groundwater sources. Sometimes considered to include flows from regulated lakes or reservoirs. Fluctuates much less than storm runoff.

Baseline Sample - A sample collected during dry-weather flow (i.e., it does does not consist of runoff from a specific precipitation event).

Basin - The term "basin" means the streams, rivers, tributaries, and lakes and the total land and surface water area contained in one of the major or minor basins defined by EPA, or any other basin unit as agreed upon by the state(s) and the Regional Administrator.

Beneficial Use of Water - The use of water for any purpose from which benefits are derived, such as domestic, irrigation, industrial supply, power development, or recreation.

Benthic Deposits - Deposits of living, bottom dwelling organisms in a stream.

Bentonite - A clay with a high content of montmorillonite. It has an expanding lattice structure which enables it to absorb large amounts of water.

Best Available Technology (BAT) - "Not later than July 1, 1983, effluent limitations for categories and classes of point sources, other than publicly owned treatment works, ...shall require application of the best available technology economically achievable for such category or class, which will result in reasonable further progress toward the national goal of eliminating the discharge of all pollutants as determined in accordance with regulations issued by the Administrator pursuant to Section 304(b)(2) of this Act...." (Act, Section 301(b)(2)(A)).

Best Practicable Control Technology (BPCT) - "Not later than July 1, 1977, effluent limitations for point sources, other than publicly owned treatment works, shall require the application of the best practicable control technology currently available as defined by the Administrator pursuant to

Section (304(b) of this Act..." (Act, Section 301(b)(1)(A). This is also referred to as Best Practical Technology (BPT).

Best Practicable Waste Treatment Technology (BPWTT) - "Waste treatment management plans and practices shall provide for the application of the best practicable waste treatment technology before any discharge into receiving waters, including reclaiming and recycling of water and confined disposal of pollutants so they will not migrate to cause water or other environmental pollution...." (Act, Section 201(b)).

Binary - The representation of a numerical quantity by use of the two digits 0 and 1.

Binary Coded Decimal (BCD) - A computer coding system.

BOD_5 - Five-day Biochemical Oxygen Demand: A standard test for the amount of oxygen utilized in aerobic decomposition of a waste material during a five-day incubation at a specified constant temperature.

Biological Treatment Processes - Means of treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Trickling filters, activated sludge processes, and lagoons are examples.

Biome - A major biotic community including all plant and animal life, e.g., the North American Boreal forest, European deciduous forest.

Bit - A basic unit of computer storage, symbolically capable of representing only a "1" or a "0".

Bituminous - Any of various natural substances consisting mainly of hydrocarbons, such as asphalt, coal tar, pitch, maltha, gilsonite, etc.

Bond - A written promise to pay a specified sum of money (called the face value) at a fixed time in the future (called the date of maturity) and carrying interest at a fixed rate, payable periodically. The difference between a note and a bond is that the latter usually runs for a longer period of time and requires greater formality.

Bond Discount - The excess of the face value of a bond over the price for which it is acquired or sold.

Bond Premium - The excess of the price at which a bond is acquired or sold over its face value.

Boreal Forest - The forest extending across northern North America, consisting chiefly of conifers.

Brackish Water - Water containing dissolved minerals in excess of acceptable normal municipal, domestic, and irrigation standards, but less than that of sea water.

Buffer Strips - Strips of grass or other erosion-resisting vegetation between or below cultivated strips or fields.

Bypass - A pipe line which diverts wastewater flows away from or around, pumping or treatment facilities - or bypasses them - in order to limit the flows delivered to such facilities and prevent surcharging or adversely affecting their operation or performance.

Byte - A few bits (typically 6 or 8, depending upon the computer) of computer storage, required to store one character.

Calibration - The procedure of assigning values to the uncertain or unknown parameters in simulation model and adjusting them until model predictions correspond acceptably closely with observed prototype behavior.

Capital Charges - The portion of annual cost due to capital expense. Its components include depreciable capital charges, nondepreciable capital charges, and amortizable capital charges.

Capital Intensive - Measure requiring initial capital outlays for its development and relatively little cost for operation and maintenance.

Capital Investment - The total original cost of installed facilities including process and ancillary facilities, indirect construction cost, land, start-up costs, and working capital.

Carrying Charge Multiplier - The sum of "Interest Rate" and "Sinking Fund Factor"; when multiplied by bond principal yields capital charge.

Catch Basin - A chamber or well, usually built at the curb line of a street, for the admission of surface water to a sewer or subdrain, having at its base a sediment sump designed to retain grit and detritus below the point of overflow.

Catchment - Surface drainage area.

Channel - An elemental one-dimensional flow path having the usual properties of a water channel, which is used to construct certain receiving water simulation models. Also used in discussing the river channel itself.

Check Dam - Small dam constructed in a gully or other small watercourse to decrease the streamflow velocity, minimize channel scour, and promote deposition of sediment.

Chemical Coagulation - The destabilization and initial aggregation of colloidal and finely divided suspended matter in wastewater by the addition of a floc-forming chemical.

Chemical Oxygen Demand (COD) - A standard test which measures the total quantity of oxygen required for oxidation of organic (carbonaceous) matter to carbon dioxide and water using a strong oxidizing agent (dichromate) under acid conditions.

Chemical Weathering - Chemical reactions such as hydrolysis, or oxidation, by which rocks and minerals are broken down into soil.

Chlorine Demand - The demand for chlorine in a volume of water caused by organic and inorganic reductants. This quantity is defined as the difference between an initial chlorine concentration in a specific volume of water and the total available chlorine remaining at the end of a contact period.

Clay - The smallest mineral particles in soil, less than .004 mm in diameter; soil that contains at least 40 percent clay particles, less than 45 percent sand, and less than 40 percent silt.

Clay Seal - A barrier constructed of impermeable clay that stops the flow of water.

Clear Cutting - The felling of all trees in an area at one time.

Closed Basin - A basin is considered closed with respect to surface flow if its topography prevents the occurrence of visible outflow. It is closed hydrologically if neither surface nor underground outflow can occur.

Cohesion - The capacity of a soil to resist shearing stress, exclusive of functional resistance.

Cohesive Soil - A soil that when unconfined has considerable strength when air-dried and significant cohesion when submerged.

Coliform Bacteria - All the aerobic and facultative anaerobic, gram-negative nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C. Used as an indicator of bacterial pollution.

Collector Sewer - A sewer located in the public way which collects the wastewaters discharged through building sewers and conducts such flows into larger interceptor sewers and pumping and treatment works. (Referred to also as "street sewer".)

Combined Sewer - A sewer receiving both surface runoff and sewage.

Commercial Forest - The forest which is both available and suitable for growing continuous crops of raw logs or other industrial timber products, judged capable of growing at least 20 ft^3 of timber per acre per year.

Compiler - A programmed component of a computer, which converts sophisticated programming language into elementary instructions and binary code.

Complete Sewer Separation - Separation of all public combined sewers into two separate and independent sewer systems, one for the handling of sanitary sewage and industrial and commercial wastes and the other for the handling of storm water flow.

Composite Sample - Any one of a number of types of integrated samples comprised of a number of sub-samples (aliquots) taken over a given time period and intended to represent average flow characteristics.

Concentration - The quantity of a given constituent in a unit volume or weight of water.

Conductivity - A measure of the ability of a material to conduct an electric current, the reciprocal of resistivity.

Confidence Interval - A mathematical method of stating both how close the value of a sample statistic is likely to be to the value of a universe parameter and the calculated or desired probability of that accuracy occurring.

Confined Aquifer - An aquifer which is bounded above and below by formations of impermeable or relatively impermeable material.

Connate Water - Water that was deposited simultaneously with the sediments, and has not since then existed as surface water or as atmospheric moisture.

Conservation - The protection, improvement, and use of natural resources according to principles that will assure their highest economic or social benefits.

Conservative Constituents - Materials carried in the hydrologic system which, on a class basis, do not interact with the chemical, physical, or biological elements of the environment to a significant extent, i.e., do not decay significantly as a function of time.

Conservative Substance - Non-interacting substance, undergoing no kinetic reaction; examples are salinity, total dissolved solids, total nitrogen, total phosphorus.

Consumptive Use (Water) - The sum of the quantity of water used by vegetative growth in transpiration or building of plant tissue and the quantity evaporated from adjacent soil or plant surfaces in a given specified time. Also referred to as Evapotranspiration.

Contamination - The degredation of natural water quality as a result of man's activities, to the extent that its usefulness is impaired.

Continuous Model - A model which simulates continuously varying processes over a long period of time, typically many years.

Contour Furrows - Furrows plowed approximately on the contour on pasture or rangeland to prevent soil loss and increase infiltration. Also, furrows laid out approximately on the contour for irrigation purposes.

Contractor's Indirect Field Costs - The contractor's construction costs for his supervision, construction equipment, small tools, consumables, temporary facilities, temporary services, support labor, insurance, taxes and miscellaneous field costs.

Convective Precipitation - Precipitation caused by lifting due to convective currents, as in thunderstorms.

Conventional Tillage - Land prepared by turning with a mold-board plow, discing, harrowing and cultivation of row crops.

Core City - The major jurisdiction within the SMSA.

Coshocton Wheel - A runoff sampler that divides the flow from an experimental area and retains a proportional part of it in a storage tank.

Cost-Effectiveness Analysis - The procedure for economic evaluation of wastewater treatment alternatives.

Coupled Constituent - A constituent whose nonconservative behavior is affected by the presence of a second constituent.

Cover Crop - A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production or between trees and vines in orchards and vineyards.

Critical Depth - The depth of water flowing in an open channel or partially filled conduit corresponding to one of the recognized critical velocities.

Critical Point - The point in a stream segment at which a water quality parameter reaches its worst value.

Curb Length - The distance of single street curb, or the length of one side of a street or other thoroughfare. Distinguished from street length which normally represents two or more curb lengths.

Degree Days - Sum of negative departures of average daily temperature from 65°F; used to determine demand for fuel for heating purposes and snow melt calculations.

Demersal Fish - The resident fish species for a particular water body.

Demineralization - The process of reducing the concentration or removing the mineral salts from water.

Demographic - Pertaining to the science of vital and special statistics, especially with regard to population density and capacity for expansion or decline.

Denitrification - The biochemical reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen.

Dependent Variable - Variable whose values are functionally determined by the independent variable.

Depletion (Ground Water) - The withdrawal of water from a groundwater source at a rate greater than its rate of replenishment, usually over an extended period of several years.

Depreciable Capital - Total plant cost less cost of land, salvage value, and working capital.

Depression Storage - Watershed capacity to retain water in puddles, ditches, depressions and on foliage.

Design Storm - A selected rainfall pattern of specified amount, intensity, duration, and frequency which is used as a design basis.

Desilting Area - An area of grass, shrubs, or other vegetation used for inducing deposition of silt and other debris from flowing water, located above a stock tank, pond, field, or other area needing protection from sediment accumulation.

Detention Dam - A dam constructed for the purpose of temporary storage of streamflow or surface runoff and for releasing the stored water at controlled rates.

Detention - The slowing, dampening, or attenuating of flows either entering the sewer system or within the sewer system by temporarily holding the water on a surface area, in a storage basin, or within the sewer itself.

Detention Time - The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of discharge).

Dielectric Constant - A measure of the ability of a material to hold a charge.

Diffusion - A process by which water quality constituents are transported, primarily depending upon the concentration gradients.

Digestion - The anaerobic or aerobic decomposition of organic matter resulting in partial gasification, liquefaction, and mineralization.

Dilution Ratio - The ratio of the quantity of combined sewer overflow or storm sewer discharge to the average quantity of diluting water available after initial mixing at the point of disposal or at any point under consideration. This is not only used with respect to sewer overflows but also it is used for any point or nonpoint sources of pollution.

Direct Capital Investment - The costs of construction associated with specific constructed equipment. This item includes purchase and installation of all equipment, buildings, and facilities and the cost (or value) of the land associated with them.

Direct Connection - Any opening, pipe, or other arrangement permitting storm water to directly enter a sanitary sewer.

Directly Connected Paved Area - The paved portion of a basin from which runoff water can reach a sewer without first passing over grassed area.

Direct Runoff - The water that enters stream channels during a storm or soon after. It may consist of rainfall on the stream surface, surface runoff, and seepage of infiltrated water.

Disinfection - The art of killing the larger portion of microorganisms in or on a substance with the probability that all pathogenic bacteria are killed by the agent used.

Dispersion - The mixing of polluted fluids with a large volume of water in a stream, estuary, or other body of water.

Dispersion, Longitudinal - The process by which prototype concentrations are changed as a result of the non-uniform velocity distribution at a channel cross-section.

Dispersion, Soil - The breaking down of soil aggregates into individual particles, resulting in single-grain structure. Ease of dispersion is an important factor influencing the erodibility of soils. Generally speaking, the more easily dispersed the soil, the more erodible it is.

Disposal Field - Area used for spreading liquid effluent for separation of wastes from water, degradation of impurities, and improvement of drainage waters. Synonymous with infiltration field.

Dissolved Solids (DS) - The total amount of dissolved material, organic and inorganic, contained in solution in water or wastes.

Distributed Load - A constituent load which enters the receiving water over a considerable distance, as in the case of groundwater seepage, rather than at a point as with a sewer outfall.

Diversity (Ecological) - Variety of species of plants and animals that compose a biotic community or ecosystem; often expressed as total number of different species.

DO - Dissolved oxygen, the amount of gaseous oxygen dissolved in a liquid sample.

DO Deficit - The extent by which the dissolved oxygen concentration falls below its saturation level.

Drainability - ability of the soil system to accept and transmit water by infiltration and percolation.

Drainage Basin - A geographical area or region which is so sloped and contoured that surface runoff from streams and other natural watercourses is carried away by a single drainage system by gravity to a common outlet or outlets; also referred to as a watershed or drainage area.

Drainage Density - Ratio of the total length of all drainage channels in a drainage basin to the area of that basin.

Drawdown - The lowering of the water table or piezometric surface caused by pumping or artesian flow.

Drop Spillway - Overall structure in which the water drops over a vertical wall onto an apron at a lower elevation.

Dry Weather Flow - The combination of sanitary sewage, and industrial and commercial wastes normally found in the sanitary sewers during the dry weather season of the year. Also that flow in streams during dry seasons.

Dual Treatment - Those processes or facilities designed for operating on both dry and wet-weather flows.

Dynamic - A process which may vary freely with time.

Dynamic Equilibrium - A process which may vary with time, but only over a limited period (e.g., one day) which repeats itself in cycles. Also known as dynamic steady state.

Dynamic Regulator - A semiautomatic or automatic regulator device which may or may not have movable parts that are sensitive to hydraulic conditions at their points of installation and are capable of adjusting themselves to variations in such conditions or of being adjusted by remote control to meet hydraulic conditions at points of installation or at other points in the total combined sewer system.

Ecosystem - A total organic community in a defined area or time frame.

Edge Effect - The influence of two communities upon their border, whereby composition, density, and diversity are affected, usually being more complex and greater than the two distinct communities (e.g., grassland bordering a woodland).

Effluent Limited Segments - "Any segment were it is known that water quality is meeting and will continue to meet applicable water quality standards or where there is adequate demonstration that water quality will meet applicable water quility standards after the application of the effluent limitations required by Sections 301(b)(1)(A) and 301(b)(1)(B) of the Act." (40 CFR 130.11(d)(2).

Effluent Limitation - "The term 'effluent limitation' means any restriction established by a State or the Administrator on quantities, rates, and concentrations or chemical, physical, biological, and other constituents which are discharged from point sources into navigable waters, the waters of the contiguous zone, or the ocean, including schedules of compliance." (Act, sec. 502 (11).

Effluent Standard - A restriction on the quantities or concentrations of constituents from an effluent source.

Emissions - Effluents discharged into the environment, specified as weight per unit time for a given pollutant from a given source.

Enterococci - A group of bacteria consisting of anaerobic spore-forming rods which indicate recent fecal pollution, sometimes referred to as fecal streptococci.

Entry Time - The time in minutes for runoff water to flow from the most remote point on the directly connected paved area to a specified inlet.

Equalization - The averaging (or method for averaging) of variations in flow and composition of a liquid.

Equivalent Days of Accumulation (EDA) - A measure of the relative days of accumulation of pollutants on a street surface as a function of rainfall and sweeping history and respective removal efficiencies.

Equivalent Uniform Depth (E.U.D.) - The average amount of rainfall over an area developed from the constituent rain gage stations and their associated Thiessen Polygons contained within the network of gaging stations.

Erosion, Sheet - The removal of a fairly uniform layer of soil from the land surface by runoff water.

Estuary - The mouth of a river, where tidal effects are evident and where fresh water and sea water mix.

Eutrophication - The progressive enrichment of surface waters particularly non-flowing bodies of water such as lakes and ponds, with dissolved nutrients, such as phospaurous and nitrogen compounds, which accelerate the growth of algae and higher forms of plant life and result in the utilization of the useable oxygen content of the waters at the expense of other aquatic life forms.

Evapotranspiration - The combined processes of evaporation from land, water, and other surfaces, and transpiration by plants.

Event Model - A model which simulates the processes occurring in just a single event, typically for a near-steady-state condition or for only one major variation during a relatively short period of time.

Exchange Coefficient - The fraction of material leaving an embayment during ebb tide, which returns on the following flood tide.

Executive Program - A program, often supplied with a computer, which controls loading and relocation of all software (much unknown to the programmer) required to execute a job entered by a programmer.

Exfiltration - The leakage or discharge of flows being carried by sewers out into the ground through leaks in pipes, joints, manholes or other sewer system structures; the reverse of "infiltration."

Extraneous Flow - That portion of the liquid carried in the sewer that is not normally classified as sanitary, commercial, or industrial waste or sewage.

Factorial Arrangement - A method for apportioning the number of tests required for an Analysis of Variance. Given the formula $N=X^k$ where X is the number of independent variables and k is the number of levels (factors).

Fecal Coliform - Fecal coliform are indicators of human and animal pollution and are expressed as numbers of bacteria per volume of sample.

Feedlot - A relatively small, confined land area for raising and fattening cattle.

Filter Strip - Strip of permanent vegetation above farm ponds, diversion terraces, and other structures to retard flow of runoff water, causing deposition of transported material, thereby reducing sediment flow.

First Flush - The condition, often occurring in storm sewer discharges and combined sewer overflows, in which a disproportionately high pollutional load is carried in the first portion of the discharge or overflow.

Floatable Trap - A device or structural configuration which intercepts floatable solids and retains these materials at a desired location until removed and disposed of by predetermined means.

Flooding - A method of surface application of water which includes border strip, contour check, and spreading methods.

Floodplain - The flat ground along a stream course which is covered by water at flood stage.

Flow Augmentation - The addition of water or wastewater effluents to surface water sources, for the purpose of increasing the volume of such waters as rivers, lakes or other inland bodies of surface water; in the case of groundwater, the addition of wastewater effluents which will increase the volume of the underground water source and raise or help maintain the groundwater table.

Fluvial Sediment - Those deposits produced by stream or river action.

Food Chain - Refers to the dependence for food of organisms upon each other in a series, beginning with plants and ending with the largest carnivores.

Food Web - The combination of all of the food chains in a community.

Form Factor (FF) - An indicator of the drainage characteristics of a watershed.

Foundation Drain - A pipe or series of pipes which collects groundwater from the foundation or footing of structures and discharges these waters into sanitary, combined or storm sewers, or to other points of disposal, for the purpose of draining unwanted waters away from such structures.

Frequency Distribution - A curve which shows the arrangement or distribution of the occurrences of events or quantities pertaining to a single element in order of their magnitude.

Frequency of Storm (Design Storm Frequency) - The anticipated period in years which will elapse, based on average probability of storms in the design region, before a storm of a given intensity and/or total volume will recur; thus a 10-year storm can be expected to occur on the average once every 10 years. Sewers designed to handle flows which occur under such storm conditions would be expected to be surcharged by any storms of greater amount or intensity.

F Value - A number corresponding to the degree of confidence of a certain statistical correlation. A correlation with an "F" less than one is generally discounted.

General Obligation Bonds - Bonds secured by the issuer's pledge of full faith, credit, and taxing power for payment.

Geomorphic Province - A region in which the majority of land features have a degree of similarity as to its origin and development.

Grade Stabilization Structure - A structure for the purpose of stabilizing the grade of a gully or other watercourse, thereby preventing further headcutting or lowering of the channel grade.

Grassed Waterway - A natural or constructed waterway, usually broad and shallow, covered with erosion-resistant grasses, used to conduct surface water from cropland.

Grease - In sewage, grease includes fats, waxes, free fatty acids, calcium and magnesium soaps, mineral oils, and other nonfatty materials. Substances soluble in n-hexane.

Grit - Heavier and larger solids which, because of their size and specific gravity, settle more readily to the floor of a swirl concentrator chamber by the phenomenon of gravity classification.

Ground Water Infiltration - The seepage of groundwater into an opening in a sewer.

Ground Water Basin - A ground water reservoir together with all the overlying land surface and the underlying aquifers that contribute water to the reservoir. In some cases, the boundaries of successively deeper aquifers may differ in a way that creates difficulty in defining the limits of the basin.

Ground Water Recharge - Inflow to a ground water reservoir.

Ground Water Reservoir - An aquifer or aquifer system in which ground water is stored. The water may be placed in the aquifer by artificial or natural means.

Ground Water Storage Capacity - The reservoir space contained in a given volume of deposits. Under optimum conditions of use, the useable ground water storage capacity volume of water that can be alternately extracted and replaced in the deposit, within specified economic limitations.

Groundwater Table - The free surface of the groundwater, that surface subject to atmospheric pressure under the ground, generally rising and falling with the season, the rate of withdrawal, the rate of restoration, and other conditions. It is seldom static.

Gully - A channel or miniature valley cut by concentrated runoff but through which water commonly flows only during and immediately after heavy rains or during the melting of snow.

Gully Control Plantings - The planting of forage, legume, or woody plant seeds, seedlings, cuttings, or transplants in gullies to establish or reestablish a vegetative cover adequate to control runoff and erosion.

Hardness - A property of water caused by the presence of calcium and magnesium, which is reflected in the amount of soap necessary to form suds and incrustations in appliances and pipes when the water is heated. It is expressed as an equivalent amount of calcium carbonate.

Hardware Computer - The physical equipment and devices which comprise a computer or computer system component.

Hard Water - Water with over 60 mg/l of hardness.

Heat Budget - The accounting of the various factors governing water temperature.

Heavy Metals - Metallic elements with high molecular weights, generally toxic in low concentrations to plant and animal life. Examples are: mercury, chromium, cadmium, arsenic, and lead.

Herbicide - A chemical substance used for killing plants, especially weeds.

Higher Hearing Value - Heat released in combustion of dry fuel where combustion gases are cooled to 66°F and all water vapor is condensed prior to release to the atmosphere.

Homogeneous - Consisting throughout of identical or closely similar material whose proportions and properties do not vary.

Humus - That more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues have decomposed; usually amorphous and dark colored.

Hydraulic Barrier - A means of augmenting the groundwater volume and raising the level of the water table in order to create hydraulic gradients higher than the level of surrounding waters which would tend to inflow or infilter into the groundwater aquifer and introduce contaminants or other unwanted substances which could adversely affect its quality.

Hydraulic Radius - A measure of the depths of flow in a conduit or channel, more formally it is the cross-sectional area of flow divided by the perimeter of the channel in contact with the fluid.

Hyetograph - An intensity-time graph for rainfall derived from direct measurements.

Hydrograph - A flow versus time graph derived from direct measurement.

Hydrological - Pertains to the branch of hydrology that treats surface and groundwater; its occurrence and movements; its replenishment and depletion; the properties of rocks which control groundwater movement and storage; and the methods of investigation and utilization of groundwater.

Hydrological Budget - An accounting of all inflow to, outflow from, and changes in storage within a hydrologic unit such as a drainage basin, soil zone, aquifer, lake, or project area.

Hydrologic Cycle - The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration.

Hydrology - The science dealing with water in the atmosphere, on the earth's surface, and underground; its properties, laws, geographical distribution, etc.

Illicit Connection - An unauthorized connection from a residence, apartment, etc., which introduces liquid other than sewage (usually stormwater) into the sanitary sewer.

Impervious - Not permitting penetration or passage (e.g., of water).

Independent Variable - A parameter which can be directly manipulated and which mathematically, has a correlation coefficient of zero.

Indirect Capital Investment - Capital costs not directly associated with or charged directly to a single cost item. Usually consists of engineering and design; constvuction expenses such as temporary construction facilities, construction equipment, tools, supplies and utilities, construction supervision and field engineering, and payroll burden; contractor's fees; plant start-up; and interest during construction.

Indirect Runoff - That portion of runoff that contributes to the runoff pollution that enters receiving water as point discharges from separate storm sewer systems and as general surface runoff.

Industrial Waste - The liquid wastes from industrial processes as distinct from domestic or sanitary sewage.

Infiltration - The water entering a sewer system, including sewer service connections, from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections, and manhole walls. Infiltration does not include, and is distinguished from, inflow. Infiltration includes all extraneous water during wet weather, i.e., groundwater and surface water.

Infiltration, Gross - The total infiltration entering a sanitary sewer by direct connections and by percolation through the soil.

Infiltration Inflow - A combination of infiltration and inflow waste water volumes in sewer lines that permits no distinction between the two basic sources and has the same effect of usurping the capacities of sewer systems and other sewerage system facilities.

Infiltration-Percolation - An approach to land application in which large volumes of wastewater are applied to the land, infiltrate the surface, and percolate through the soil pores.

Infiltration Rate - A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water.

Infiltration Specification - A condition for acceptance of a sanitary sewer from a contractor by a sewer authority. This specification limits the amount of infiltration acceptable in a sewer system.

Inflow - The water discharged into a sewer system, including service connections, from such sources as, but not limited to, roof leaders, cellar, yard and area drains, foundation drains, cooling water dischargers, drains from spring and swampy area, manhole covers, cross connections from storm sewers and combined sewers, catch basin, surface runoff, street wash waters, or drainage. Inflow does not include, and is distinguished from, infiltration.

Initial Abstraction - Initial precipitation loss including interception and depression storage.

Inplace Pollution Source - Time build-up of pollutant load deposited in a receiving stream-bed and existing as a load upon that receiving water.

In-System Storage - Facilities or the capacity for holding or retaining of flows of sewage and other wastes in subterranean storage chambers or other portions of the sewer system in order to minimize overflows from combined sewers and permit the treatment of large volumes of such flows.

Intercepted Surface Runoff - That portion of surface runoff that enters a sewer, either storm or combined, directly through catch basins, inlets, etc.

Interception Ratio - Pertaining to combined sewer regulators, it is the ratio of the maximum flow which can be directed to the interceptor sewer to the normal dry-weather flow.

Interceptor Sewer - A sewer which receives dry-weather flows from a combined collection sewer system and pre-determined additional amounts of storm flow by means of any form of regulating device and then conducts these flows to point by treatment or discharge.

Invert - The lowest point on the inside of a sewer or other conduit.

Irrigation Return Flow - Irrigation water which is not consumed in evaporation or plant growth, and which returns to a surface stream or groundwater reservoir.

Isoquants - Curves representing combinations of the inputs yielding the same amount of output.

Junction - In rivers, the point of connection of two upstream stretches or segments. In some estuary models a junction is a segment of the estuary.

Kinetics - The dynamics of physical, chemical and biological reaction processes. Distinct from kinematics in that mass effects are considered.

Lacustrine - Deposits which have accumulated in lakes or marshes.

Lagoon - A shallow pond, usually man-made, to treat municipal or industrial wastewater.

Land Application - The discharge of wastewaters onto land areas, as an alternative treatment procedure to conventional method or disposal of effluents into surface water sources.

Land Cost - Cost of land acquisition including surveys, condemnation proceedings, fees, taxes, leases, and other financial and legal actions.

Land Subsidence - The lowering of the natural land surface in response to earth movements; lowering of fluid pressure; removal of underlaying supporting material by mining or solution of solids, either artificially or from natural cuases; hydrocompaction; etc.

Land Use - Differentiating the spatial arrangements and activity patterns of land areas.

Land Use Controls - Methods for regulating the uses to which a given land area may be put, including such things as zoning, subdivision regulation, and flood-plain regulation.

Lateral Sewer - A sewer which receives wastes only from the house connections.

Leachate - The liquid that has percolated through the soil or other media and has extracted dissolved or suspended materials from it.

Leaching - The removal of chemical or physical components from soil or other media by dissolution or physical adsorption action of percolating water.

Linked Constituent - A constituent whose nonconservative behavior is affected by the presence of one or more other constituents.

Limited Body Contact Recreation - Use of natural waters, such as rivers, lakes, and coastal waters, for recreational purposes which do not represent deliberate or planned total body immersion such as swimming or bathing; thus, use of waters for boating, fishing, and related sports.

Loading - The dry weight, in pounds, of some material that is being added to a process or disposed of.

Loadograph - A graph of pollutant load as a function of time over a defined period of time (pollutograph).

Logic - The science of combining electronic components in order to define the interactions of signals in an automatic data processing system.

Main Sewer - A sewer to which one or more branch sewers are tributary and which serves a large territory; also called a trunk sewer.

Materials Balance - An accounting of all transfers of mass from one point or state to other points or states, such that the total original mass is entirely accounted for (Also Mass Balance).

Mathematical Model - The characterization of a process or concept in terms of mathematics, which allows the manipulation of variables in an equation to determine how the process would act in different situations.

Mean Velocity - The average velocity of a stream flowing in a channel or conduit at a given cross section or in a given reach. It is equal to the discharge divided by the cross-sectional area of the reach.

Mechanical Practices - Those management techniques for soil and water conservation that primarily change the surface of the land or that store, convey, regulate, or dispose of runoff water without excessive erosion.

Mesophyte - A plant growing under conditions of well-balanced moisture supply, as distinguished from one which grows under dry or desert conditions (xerophytes) or very wet conditions (hydrophytes).

Microstrainer - Variable low-speed (up to 4 to 7 rpm), continuously backwashed, rotating drum filters operating under gravity conditions.

Mineralization - The process of accumulation of mineral elements and/or compounds in soil or water.

Mixing Intensity - The degree of turbulence created by the expenditure of mechanical energy.

Most Probable Number (MPN) - A statistical indication of the number of bacteria present in a given volume (usually 100 ml).

Mulching - The addition of materials (usually organic) to the land surface to curtail erosion or retain soil moisture.

Multiple Tube Technique - A technique to determine the density of coliform bacteria in a given volume of water carried out by dividing the sample into multiple portions and testing each portion individually.

Municipal Bonds - Bonds issued by a state, territory, or possession of the United States, or by any municipality, political subdivision, or public agency or instrumentality.

Natural Erosion - Wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, etc., undisturbed by man.

Natural Leaching - The removal by a solvent of the more soluble minerals in soil or rocks by percolating waters.

Neutralization - The process of adding an acid or alkaline material to waste water to adjust its pH to a neutral position of 7.0.

Nitrate (NO_3) - A form of nitrogen which is an essential nutrient to plants (can cause algal blooms if all other nutrients are present in sufficient quantities). Product of bacteria oxidation of other forms of nitrogen, from the atmosphere during electrical storms and from fertilizer manufacturing.

Nitrification - The biological oxidation of ammonium salts to nitrites and the further oxidation of nitrites to nitrates.

Nitrogen (Ammonia) - A product of microbiologic activity sometimes accepted as evidence of sanitary pollution in surface waters.

Nitrogen, Available - Usually ammonium, nitrite, and nitrate ions, and certain simple amines are available for plant growth. A small fraction of organic or total nitrogen in the soil is available at any time.

Nonconservative Constituent - A constituent whose total mass undergoes time-dependent interaction in receiving waters through physical, chemical or biological reactions.

Nondepreciable Capital - Land and working capital and salvage value of depreciable capital.

Nonpoint Source Pollution - A pollutant which enters a water body from diffuse origins on the watershed and does not result from discernible, confined, or discrete conveyances.

Nonsewered Urban Runoff - Surface runoff in an urban drainage area which drains into a receiving stream without passing through a sewer system.

Non-Stationary Source - Mobile activity which produces air pollutant emissions.

Numerical Dispersion - Error in models using numerical approximations, caused by the use of grids of discrete size. Also called discretization error.

Nutrient - A substance necessary for the growth and reproduction of organisms.

Nutrient, Available - That portion of any element or compound in the soil that can be readily absorbed and assimilated by growing plants.

Off-System Storage - Facilities for holding or retaining excess flows from combined sewers, over and above the carrying capacity of the interceptor sewers, in chambers, tanks, lagoons, ponds, or other basins which are not a part of the subsurface sewer system.

Organic Nitrogen - Nitrogen combined in organic molecules such as protein, amines, and amino acids. Gradually converted to ammonia-nitrogen and to nitrites and nitrates if aerobic conditions prevail.

Outfall - The point, location, or structure where wastewater or drainage discharges from a sewer to a receiving body of water.

Overflow - A pipe line or conduit device, together with an outlet pipe, that provides for the discharge of portions of combined sewer flows into receiving waters or other points of disposal, after a regulator device has allowed the portion of the flow which can be handled by interceptor sewer lines and pumping and treatment facilities to be carried by and to such water pollution control structures.

Overland Flow Irrigation - A process of land application of wastewater which provides spray distribution onto gently sloping soil of relatively impervious nature, such as clays, for the purpose of attaining aerobic bio-treatment of the exposed flow in contact with ground cover vegetation, followed by the collection of runoff waters in intercepting ditches or channels and the return of the wastewater back to the spray system or its discharge into receiving waters; sometimes called spray runoff.

ORP - Oxidation Reduction Potential: A measurement of relative concentrations of oxidants and reductants in solution.

Oxidation Pond - A basin for the retention of wastewater, on a batch or continuous flow basis, where organic materials can undergo aerobic stabilization in the presence of adequate oxygen made available by either natural or various mechanical means of aeration and mixing.

Partial Separation - Removal of some portion of all the elements of storm drainage into a combined sewer; e.g., streets and parking areas only, leaving roof and foundation drainage to enter the combined sewer.

Pathogen - A microorganism capable of causing disease.

Percolation - The movement of water beneath the ground surface both vertically and horizontally, but above the groundwater table.

Perennial Yield (Ground Water) - The amount of usable water of a ground water reservoir that can be withdrawn and consumed economically each year for an indefinite period of time. It cannot exceed the natural recharge to that ground water reservoir.

Periodic Flushing - Systematic introduction of liquid into sewers at relatively high rates.

Permeability Coefficient - The volume of water, in cubic feet, under a head of one foot, that will pass through a square foot of porous surface in one day.

Pervious - Allowing movement of water.

Pesticides - Chemical compounds used for the control of undesirable plants, animals, or insects. The term includes insecticides, herbicides, algalcides rodent poisons, nematode poisons, fungicides, and growth regulators.

Phosphorus, Available - Inorganic phosphorus which is readily available for plant growth.

Photogrammetry - The science of making surveys and maps through the use of photographs.

Physical-Chemical Treatment - A method of semi-advanced or advanced wastewater treatment which combines the use of chemicals, such as activated carbon or lime, to induce reactions such as coagulation, absorption or adsorption of pollutional substances, with processes which physically remove unwanted contaminants by such means as straining, screening, settling or filtering.

Physiographic Province - A region, all parts of which are similar in geologic structure and climate and which consequently has a unified geomorphic history.

Pipe Tests - Various methods for testing sewer lines (after construction and in service) to ascertain whether or not infiltration allowances have been met, and locating the sources of infiltration that exceed construction specifications. Such tests include infiltration tests, exfiltration tests, air tests, and such means as smoke bomb tests to locate sources of infiltration in new and existing sewer lines.

Planning Process - Strategy for directing resources, establishing priorities, scheduling actions, and reporting programs toward achievement of program objectives.

Plant Operating Factor - The ratio of average annual volume flow of wastewater divided by design capacity annual flow of wastewater.

Plug Flow - The passage of liquid through a chamber such that all increments of liquid move only in the direction of flow and at equal velocity.

Plume - An area of contaminated water originating from a point source and influenced by such factors as the local water flow pattern, density of pollutant, and characteristics of the dissimilar streams.

Point Source - "The term 'point source' means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged." (Act, Section 502(14).

Pollutant - "The term 'pollutant' means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water." (Act, Section 502(6).

Pollution Parameters - The physical, chemical, and bacterial contaminants which can be quantified to indicate pollution levels.

Pollutograph - A graph of pollutant concentration as a function of time during a rainfall/runoff event.

Polychlorinated Biphenyls (PCB) - Organochlorine compounds of a pesticidal nature which are usually used for industrial purposes (such as plastic manufacture).

Population Equivalent of Industrial Wastewater - The calculated number of people contributing sewage equal in strength to a unit volume of the wastes discharged into a sewer system, in terms of biochemical oxygen demand; a common base for computing the population equivalent is that one person contributes 0.17 pounds of 5-day BOD in the form of sanitary sewage per day.

Porous Pavement - A pavement through which water can flow at significant rates.

Practice Factor "P" - A factor based on a maximum value of 1.0 that reflects the effectiveness of supporting conservation practices in controlling erosion. The factor is used in the Universal Soil Loss Equation.

Pretreatment - The removal of material such as gross solids, grit, grease, and scum from sewage flows prior to physical, biological, or physical-chemical treatment processes to improve treatability. Pretreatment may include screening, grit removal, skimming, preaeration, and flocculation.

Primary Treatment - Processes or methods, that serve as the first stage treatment of sewage and other wastes intended for the removal of suspended and settleable solids by gravity sedimentation; provides no changes in dissolved and colloidal matter in the sewage or wastes flows.

Probability Curve - A curve that expresses the cumulative frequency of occurence of a given event, based on an extended period of past occurrences.

Production Well - A well from which ground water is obtained.

Proprietary Model - A computer model developed privately by a consultant/contractor who charges for its use.

Purging - The act of reversing flow or using high pressure liquid or gas to clear a pipeline of a plug of solids.

R Value - Multiple regression value: The correlation value to many independent variables with a single dependent variable, e.g., air temperature and solar radiation on water temperature.

Rainfall Intensity - The rate at which rain is falling at any given instant, usually expressed in inches per hour.

Rational Method - A means of computing storm drainage flow rates (Q) by use of the formula Q=ciA; where c is a coefficient describing the physical drainage area, i is the rainfall intensity and A is the area.

Raw Sewage Sludge - The accumulated suspended and settleable solids of sewage deposited in tanks or basin mixed with water to form a semi-liquid mass.

Reach - The smallest subdivision of the drainage system consisting of a uniform length of open channel or underground conduit. Also, a discrete portion of river, stream or creek. For modeling purposes a reach is somewhat homogeneous in its physical characteristics.

Reaeration - The process entraining air in liquids such as wastewater effluents, etc. Reaeration is proportional to the dissolved oxygen deficit; its rate will increase with increasing deficit.

Real Time Control - The remote control of sewerage systems by digital computer. Can either be fully automated or can be partially manually controlled by the computer operator.

Recharge Basin - A basin provided to increase infiltration for the purpose of replenishing ground water supply.

Regulator - A structure installed in a canal, conduit, or channel to control the flow of water or wastewater at intake, or to control the water level in a canal, channel, or treatment unit. In the context of combined sewers, a regulator is a device or apparatus for controlling the quantity and quality of admixtures of sewage and storm water admitted from a combined sewer collector sewer into an interceptor sewer or pumping or treatment facility, thereby determining the amount and quality of the flows discharged through an overflow device to receiving waters, or to retention or treatment facilities.

Relative Correlation - A measure of the ability of a general relationship to predict the value of an experimental parameter.

Relief Ratio - The ratio between the relief (maximum difference in elevation) of watershed and the maximum length of watershed.

Residential Density - The number of persons per unit of residential land area. Net density includes only occupied land. Gross density includes unoccupied portions of residential areas, such as roads and open space.

Residual Wastes - Those solid, liquid, or sludge substances from man's activities in the urban, agricultural, mining and industrial environment which are not discharged to water after collection and necessary treatment.

Retention - The storage of stormwater to prevent it from entering the sewer system; may be temporary or permanent.

Return Flow - That part of a diverted flow which is not consumptively used and which returns to a source of supply (surface or underground).

Riparian Rights - A principle of common law which requires that any user of waters adjoining or flowing through his lands must so use and protect them that he will enable his neighbor to utilize the same waters undiminished in quantity and undefiled in quality.

Riprap - Rough stone of various sizes placed compactly or irregularly to prevent erosion.

Roof Leader - A drain or pipe that conducts storm water from the roof of a structure, downward and thence into a sewer for removal from the property, or onto or into the ground for runoff or seepage disposal.

Routine - A sequence of computer instructions which performs a specific computational function within a larger program.

Routing - Storing, regulating, diverting or otherwise controlling the peak flows of wastewater through a collection system according to some prearranged plan.

Runoff - That portion of the precipitation on a drainage area that is discharged from the area in stream channels.

Runoff Coefficient - Fraction of rainfall that appears as runoff after subtracting depression storage and interception. Typically accounts for infiltration into ground and evaporation.

Sag Curve - A curve which describes the gradual drop to some minimum value followed by an increase to normal levels of the dissolved oxygen in a flowing stream following the addition of some oxygen demanding material such as sewage.

Salinity - Salt content concentration of dissolved mineral salts in water or soil.

Salinization - The process of accumulation of soluble salts in soil or water.

Salt Water Barrier - A physical facility or method of operation designed to prevent the intrusion of salt water into a body of fresh water. In underground water management a barrier may be created by injection of relatively fresh water to create a hydraulic barrier against salt water intrusion.

Salt Water Intrusion - The invasion of a body of fresh water by salt water. It can occur either in surface or groundwater bodies.

Salt Wedge - A wedge shaped volume of salt water beneath a body of fresh water where a river and ocean meet in an estuary area.

Sanitary Sewer - A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground, storm, and surface waters that are not admitted intentionally.

Scour - The clearing and digging action of flowing air or water, especially the downward erosion by stream water in sweeping away mud and silt on the outside of a curve or during a flood.

Scum Ring - A circular plate or baffle encircling the overflow weir, located at a predetermined distance from the weir and at a depth that will cause it to retain floatables and scum and prevent them from passing over the weir crest with the clarified liquid.

Secchi Disk - A disk, painted in four quadrants of alternating black and white, which is lowered into a body of water. The measured depth at which the disk is no longer visible from the surface is a measure of relative transparency.

Secondary Treatment - Processes or methods for the supplemental treatment of sewage and other wastes, usually following primary treatment, to effect additional improvement in the quality of the treated wastes by biological means of various types, including activated sludge treatment or trickling filter treatment; designed to remove or modify organic matter. Treatment of wastewater which meets the standards set forth in 40 CFR 133.

Section - A portion of a river basin, generally larger than a segment, which is bounded by headwaters or major river junctions.

Sedimentation - The process of subsidence and deposition of suspended matter carried by water, sewage, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point where it can transport the suspended material.

Sediment Delivery Ratio - The fraction of the soil eroded from upland sources that actually reaches a continuous stream channel or storage reservoir.

Seepage Rate - Calculated from the porous permeability coefficient, is the inches of rain that would pass through porous pavement in one hour, with no water standing on the surface. A head exists due to the thickness of the pavement.

Segment - A discrete portion of a water body of somewhat homogenous character, as represented in mathematical models.

Separate Sanitary Sewer - A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants and institutions, together with minor quantities of ground, storm and surface waters that are not admitted unintentionally.

Separate Storm Sewer - A sewer that carries storm water and surface waters, street wash and other wash waters, or drainage, but excludes domestic wastewater and industrial wastes.

Service Life - The period during which the use of a property is economically feasible; synonymous with "economic life" and "useful life."

Sewer-Use Ordinance - A regulation, code, or ordinance enacted by a jurisdiction to specify the types and volumes of waste waters that can be discharged into sewer system, the waste waters that cannot be so discharged, and the fees or charges to be imposed for the privilege of discharging those wastes and volumes which are permitted.

Side Weir - A regulator which is essentially a long slot cut into the side of a sewer. Normal dry weather flow continues through the sewer while the increased depth during a storm will allow excessive flows to exit through the slot to some alternate point as an overflow.

Simulation - Representation of physical systems and phenomena by computers, models and other equipment.

Single Process Unit - A water treatment facility designed and constructed to carry out one or more steps in the wastewater treatment process; if geographically distinct, usually defined by all facilities within the battery limit. Includes all equipment, instrumentation, piping, accessory electrical equipment, plant site improvement, plant structures, and buildings directly associated with the unit.

Singular Constituent - A constituent whose behavior is not affected by the presence of other constituents.

Sinking Fund Bonds - Bonds issued under an agreement which requires the utility to set aside periodically a sum which, with accrued earnings, will be sufficient to redeem the bonds at their stated date of maturity.

Sludge Digestion - A process by which organic or volatile matter in sludge is gasified, liquefied, mineralized, or converted into more stable organic matter through the activities of living organisms.

Sluice Gate - A vertically sliding gate of any shape used to control or shut off flow in a sewer or other channel.

SMSA - Except in the New England states, a standard metropolitan statistical area is a county or group of contiguous counties which contain at least one city of 50,000 inhabitants. In the New England states, SMSA's consist of towns and cities instead of counties.

Soft Water - Water containing 60 mg/l or less of hardness.

Spoiler (Energy Dissipating Baffle) - A plate or structural plane constructed from the scum ring to the weir plate in a swirl concentrator chamber for the purpose of preventing or dampening the development of free vortex flow conditions and minimizing agitation and rotational flow over the discharge weir.

Spray Irrigation - The application of wastewater to land areas by means of stationary or moving sprays which distribute the liquid in sheet, particle or aerosol mist form.

Stability - A characteristic of numerical models. Unstable models develop large numerical errors as computations proceed. Numerical errors reduce in stable models as computations proceed.

Stabilized Grade - The slope of a channel at which neither erosion nor deposition occurs.

Standard Methods - Methods of analysis of water sewage and sludge approved by a Joint Committee by the American Public Health Association, American Water Works Association, and Federation of Sewage Works Association.

Static Regulator - A regulator which has no moving parts or has movable parts which are insensitive to hydraulic conditions at the point of installation and which are not capable of adjusting themselves to meet varying flow or level conditions in the regulator-overflow structure.

Steady-State - Quantities (e.g., inputs and solution) which do not vary with time (but may vary over space).

Step Function - A mathematical function that rises in zero time to unity and remains at unity for all time (a normalized D.C. voltage, for example).

Stepwise Regression - A statistical technique whereby a sequence of linear regression equations are computed in a stepwise manner, e.g. each independent variable is entered into the equation as it becomes the greatest remaining effect upon the variability of the dependent variable.

Stochastic - The property of being random with respect to time.

Storm Frequency - The time interval between major storms of predetermined intensity and volumes of runoff for which storm sewers and combined sewers, and such appurtenant structures as swirl concentrator chambers, are designed and constructed to handle hydraulically without surcharging and backflooding; e.g, a five-year, ten-year or twenty-year storm.

Storm Sewer - A sewer which carries storm water and surface water, street wash and other wash waters or drainage, but excludes sewage and industrial wastes. (Also called a Storm Drain).

Storm Water Infiltration - The entrance of stormwater into a sanitary sewer.

Subarea - A subdivision of a subcatchment (generally based upon a single land use but may be identical to a subcatchment).

Sub-Basin - A physical division of a larger basin which is associated with one reach of the storm drainage system.

Subcatchment - A subdivision of a drainage basin (generally determined by topography and pipe network configuration).

Subdrain - A pervious backfilled trench containing a pipe or stone for the purpose of intercepting groundwater or seepage.

Subroutine - Computer programming terminology which refers to a small program for an operation that is repeated many times within the main program.

Surcharge - The flow condition occurring in closed conduits when the hydraulic grade line is above the crown of the sewer.

Surface Runoff - Precipitation that falls onto the surfaces of roofs, streets, ground, etc., and is not absorbed or retained by that surface, thereby collecting and running off.

Telemetry - Data transmission over long distances via telephone or telegraph lines by electromagnetic means.

Terrace - An embankment or combination of an embankment and channel constructed across a slope to control erosion by diverting or storing surface runoff instead of permitting it to flow uninterrupted down the slope.

Tertiary Treatment - A third stage of treatment of sewage and other wastes, following primary and secondary treatment, for the purpose of further improving the quality of the treated waters by the removal or modification of constituents which have not been removed or modified by previous treatment steps.

Thermocline - A layer in a thermally stratified body of water in which the temperature changes rapidly within a small increment of depth relative to the remainder of the water body.

Thiessen Polygon - A device for determining the zone within which data taken at a rain gage station are applicable in a network of gaging stations.

Tidal Averaging - Averaging of processes such as water currents and pollutant transport over an entire tidal cycle. This averaging may reduce or eliminate the need to solve for time variations in tidally influenced waters.

Time Sharing - Use of a computer or device for two or more purposes during the same overall time interval, done by interspersing component actions in time.

Topographic Factor "LS" - A dimensionless factor used in the Universal Soil Loss Equation to represent the combined effects of slope length and steepness.

Topography - General term to include characteristics of the ground surface such as plains, hills, mountains; degree of relief, steepness of slopes, and other physiographic features.

Total Dissolved Solids - The dissolved salt loading in surface and subsurface waters.

Total Solids - The solids in water, sewage, or other liquids. It includes the dissolved, filterable, and nonfilterable solids.

Toxic Metals - Any metal substances in wastewater which could be toxic or poisonous to grasses, to crops, or to groundwater, and which could adversely affect those who ingest or imbibe these substances; common examples of toxic metals are copper, cadmium and boron.

Transient - A temporary and brief time-varying solution during readjustment to equilibrium or dynamic equilibrium, resulting from a sudden change in input(s).

Transpiration - The process by which plants of all types of agricultural, horticultural and silvicultural growths dissipate water or moisture into the atmosphere from stomata of leaves or other surfaces, in the form of a vapor; dissipation of water by direct evaporation from the surface of plants, bark or other membranes, stomata, and lenticula into the atmosphere.

Trickling Filter - A filter consisting of an artificial bed of coarse material, such as broken stone, clinkers, slate, slats, brush, or plastic materials, over which sewage is distributed or applied in drops, films, or spray from troughs, drippers, moving distributors, or fixed nozzles, and through which it trickles to the underdrains, giving opportunity for the formation of zoogleal slimes which clarify and oxidize the sewage.

Ultimate Oxygen Demand - The total amount of oxygen that is utilized by bacteria in the decomposition of sewage. This includes both the carbonaceous BOD and nitrogenous BOD.

Uncontrolled Storage - Storage not controlled by any remotely operated gates but depending entirely on weir or river elevations.

Underdrain System - A system of pipes or ducts, placed underground, to intercept and collect percolated wastewaters and to return these waters to a predetermined location for a predetermined purpose, often to prevent the discharge of such underground water into water sources which it is intended to protect.

Universal Soil Loss Equation - Predicts the short-term rates of soil loss for localized areas. This equation takes into account the influence of the total rainfall energy for a specific area rather than rainfall amount.

Urbanized Area - Central city, or cities, and surrounding closely settled territory. Central city (cities) have population of 50,000 or more. Peripheral areas with population density of 1,000 persons per acre or more are included.

Urban Runoff - Surface runoff from an urban drainage area that reaches a stream or other body of water or a sewer.

Vadose Water - Groundwater suspended or in circulation above the normal groundwater table.

Velocity Gradient - The unit measure of mixing intensity. It is defined as the difference in velocity of two parallel planes of fluid divided by the distance between the two planes, and has the dimensions of $\frac{ft/sec}{ft}$.

Verification (model) - The act of testing a model's accuracy using a different simulation period, i.e., an independent set of input and output data, from that used in calibration.

Virus - Any of a group of ultramicroscopic biological infectious agents that reproduce only in living cells; therefore considered evidence of human pollution.

Volatile Solids - The quantity of solids in water, sewage or other liquid lost on ignition of the total solids at 600°C.

Waste Load Allocation - A waste load allocation for a stream segment is the assignment of target pollutant loads to point and nonpoint sources so as to achieve water quality standards in the most effective manner.

Wastewater Reclamation - The process of treating salvaged water from municipal, industrial, or agricultural wastewater sources for beneficial uses, whether by means of special facilities or through natural processes.

Water Control (Soil and Water Conservation) - The physical control of water by such measures as conservation practices on the land, channel improvements, and installation of structures for water retardation and sediment detention.

Water Desalination - The removal of dissolved salts from a saline water supply.

Water Quality - A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Water Quality Limited Segments - "Any segment where it is known that water quality does not meet applicable water quality standards, and is not expected to meet applicable water quality standards even after the application of the effluent limitations required by sections 301(b)(1)(A) and

301(b)(1)(B) of the Act." (40 CFR 130.11 (d)(1)).

Water Right - A legally protected right to take possession of water occurring in a water supply and to divert that water and put it to beneficial use.

Watershed - The region drained by or contributing water to a stream, lake, or other body of water.

Water Table - The upper surface of the free groundwater in a zone of saturation except when separated by an underlying of groundwater by unsaturated material.

Water-Table Aquifer - An aquifer containing water under water-table conditions.

Wet-Weather to Dry-Weather Ratio - An "indicator" of the capacity of an interceptor sewer, as designed to carry the higher flows resulting from periods of storm, compared to the capacity provided by design to handle flows during dry weather.

Wet Weather Flow - A combination of dry weather flows, infiltration, and inflow which occurs as a result of rainstorms.

Windbreak - (1) A living barrier of trees or combination of trees and shrubs located adjacent to farm or ranch headquarters and designed to protect the area from cold or hot winds and drifting snow. Also headquarters and livestock windbreaks. (2) A narrow barrier of living trees or combination of trees and shrubs, usually from one to five rows, established within or around a field for the protection of land and crops. May also consist of narrow strips of annual crops, such as corn or sorghum.

Zero Pollution - A degree of pollution control or prevention which eliminates the addition of any contaminants or unwanted foreign material into surface water sources; incorrectly interpreted as "zero discharge" of any effluents into watercourses (land application of wastewater effluents has been suggested as one means of establishing "zero pollution" conditions).

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